TIMBER

Man's timber demands have increased greatly in the last century but his wood harvest has not. The technology of modern sawmills has ensured more efficient use of raw materials and processing of all its 'waste'

ZEFA

***Floating logs** is often the cheapest way of transporting them. In remote areas, with no other river traffic, logs can be carried downstream by fast flowing rivers. Or logs can be tied in bundles and harnessed for towing by tugs over still waters.*

WOOD IS TOUGH, DURABLE and plentiful. It can be cut into any shape and has an attractive appearance. Not surprisingly, then, it is the world's most widely used natural material.

The wood of a tree has two important functions. It conducts water from the roots up to the leaves and it strengthens the trunk, enabling it to remain upright. Wood formation begins in a small green shoot. Inside the shoot are water-conducting cells contained in several bundles, known as vascular bundles. These are arranged in a ring around the inside of the shoot.

Water-conducting cells

The cells, known as xylem cells, are tube-shaped. The cell walls, like the walls of all plant cells, are made of the chemical cellulose, but in xylem cells

ZEFA

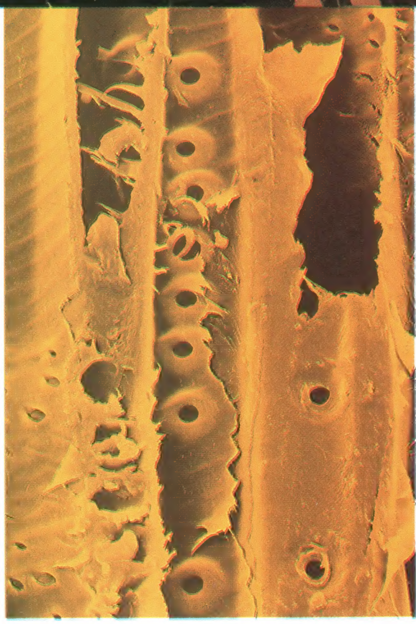
the walls are additionally thickened and strengthened with a substance called lignin. Each vascular bundle also contains food-conducting cells, called phloem cells, which lie on the outside of the bundle and are separated from the xylem cells by a layer of cells known as the cambium.

Growing layer

As the shoot grows larger, the cambium of each bundle links up with the cambium in the bundles on either side of it, to form a cylinder. The cambium

...ldi/Jerrican

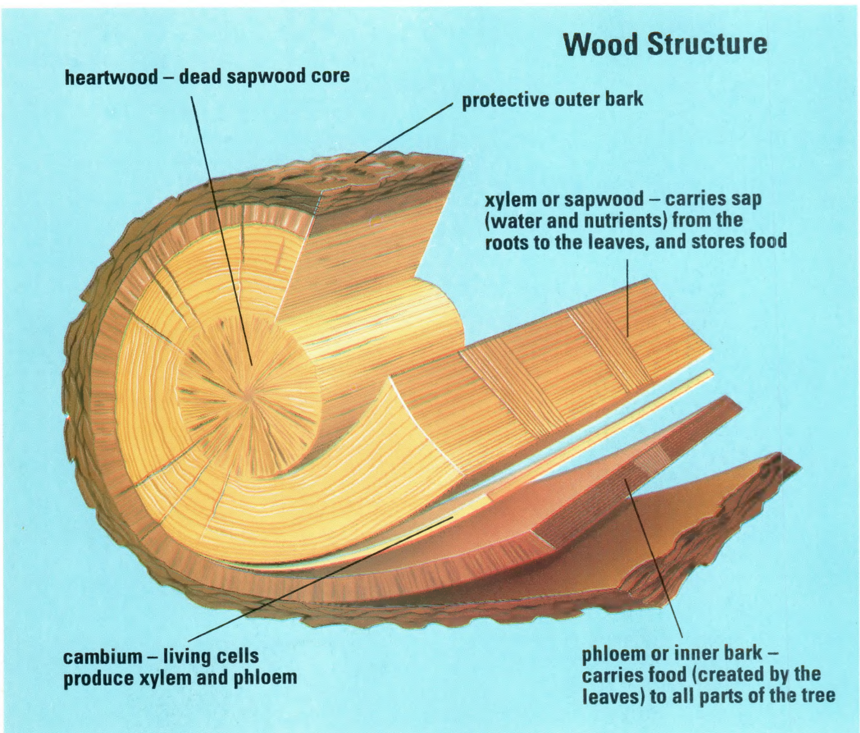
cells start to divide, producing new xylem cells on the inside of the cylinder and new phloem cells on the outside.



Dr Jeremy Burgess/Science Photo Library

***Debarking tree trunks** is the first function of the sawmill. This process is often computerized (far right). A vertical section through a Scots pine (right, magnification x 100). In softwoods, these tubes, or tracheids, conduct sap (water and nutrients) and give support to the tree. The tiny holes or 'pits' allow sap to pass between cells.*

***A section of a tree stem** shows the growing cambium layer. This produces xylem cells on the inside that form the tree's heartwood and phloem cells on the outside that form the bark.*



Joe Lawrence

Heartwood

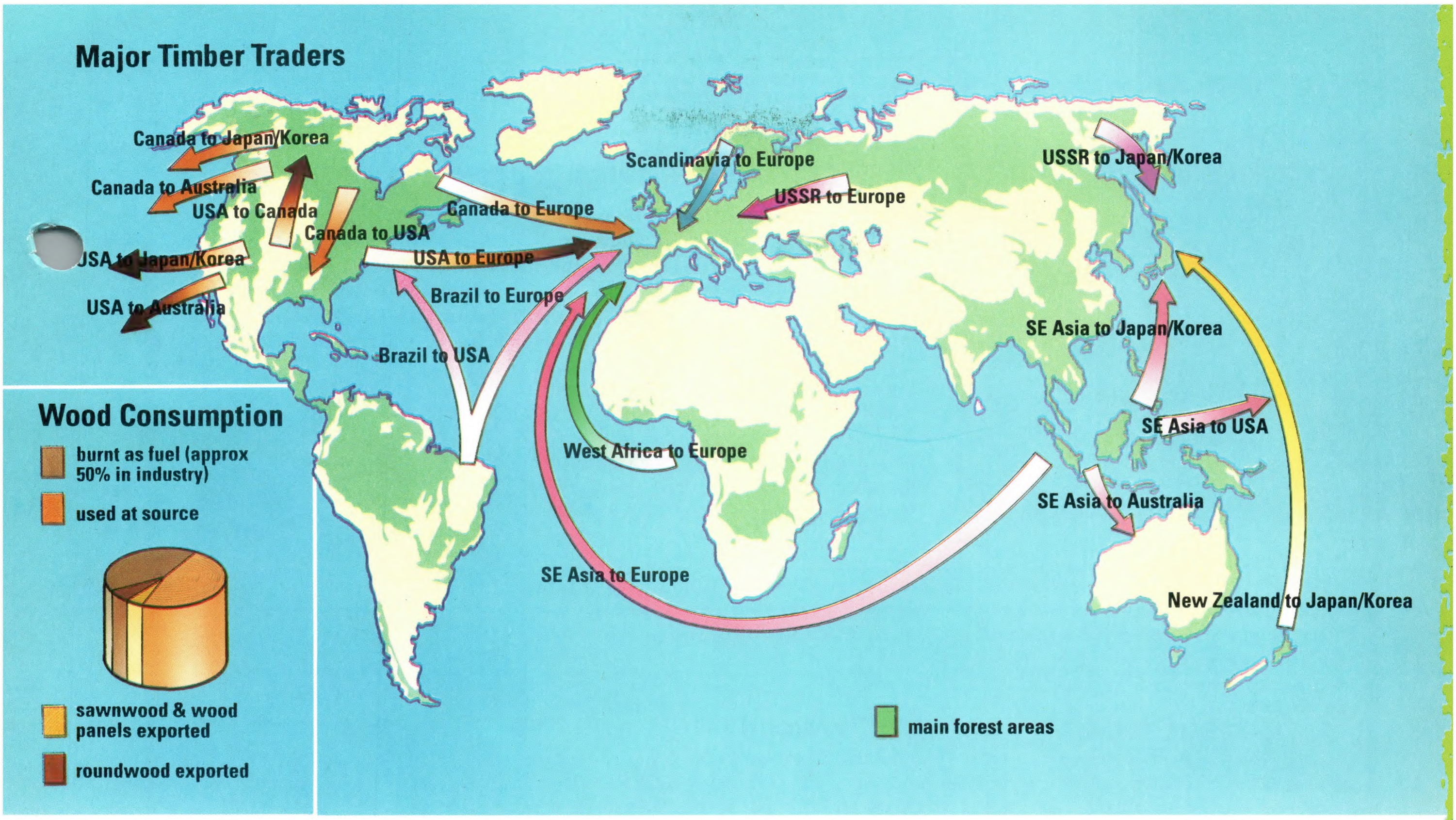
The tough xylem cells form a layer of wood that becomes thicker and thicker as the years pass. However, only the most recently formed wood is used for water-conduction. The wood at the centre tends to fill up with minerals and forms the heartwood. The layer of phloem does not build up. The thin-walled cells are replaced with new ones each year. In order to protect the vulnerable phloem cells, a thick bark develops on the outside of the tree.

Seasonal growth

Wood formation does not necessarily go on all the time. In temperate climates, trees form new wood only during spring and summer. While cells formed in the spring are large, those formed later get progressively smaller until cell formation ceases completely in late summer. Next spring, wood formation begins again and there is a sudden change from small, late summer cells to large spring cells.

Tree rings

In a tree stump or felled trunk these cells show as light and dark rings (see PLANET EARTH page 68). By counting these annual rings, you can find out the age of a tree when it was felled. In rainy years, trees will produce a lot of sapwood, creating wide rings, and in dry years trees will form



***World trade in timber** accounts for a small percentage of the wood Man uses annually – a staggering 3,352 million cubic metres in 1987.*

ENGINEERED WOOD

Wood without knots and lumps of resin is known as clear lumber. Builders prefer to use this for surfaces that have to withstand all kinds of weather. But clear lumber is becoming scarce. World wood supplies have been used at a faster rate than they can be replaced for the last thousand years. Softwoods are not in danger – coniferous trees grow fairly rapidly – but hardwoods are beginning to disappear. Scientists in the USA have devised an alternative particle board: wood chips are first reduced to a fibrous pulp that is then mixed with wax and plastic (phenolic resin); the mixture is heated and pressed into a board that looks similar to natural wood but is waterproof and does not decay, warp or crack.

smaller, compacted, dark rings. By studying these rings – a science known as dendrochronology – scientists have built up a picture of world climates stretching far back in history.

Wood fibre

Woods are classified in two main groups – softwoods and hardwoods. Softwoods come from coniferous trees, such as pine, spruce and fir. Their xylem cells are known as tracheids and those produced in the summer have thicker walls than the spring cells. These late summer cells provide most support for the tree.

Hardwoods come from broadleaved trees, such as oak, beech, teak and poplar. Their support is provided by many small fibres. Their water-conducting cells are much larger and, if the end of a cut stem or branch is examined closely, they can be seen as a number of tiny holes, which are called pores.

Wood is processed at a sawmill. Each log is debarked and then either pulped for paper or cut up into squared off timbers and planks by mechanical saws. The boards are then graded for quality and stacked.

Seasoning

Before this wood can be used, it has to be dried, or seasoned, in order to remove the sap. Unseasoned wood is prone to shrinking and warping. Seasoning can simply be done by allowing the wood to dry out naturally over a period of a year or so. However, drying timber in a kiln is quicker and more reliable.

A great deal of softwood is pulped for making into paper and board. All kinds of wood are processed for buildings, furniture, boats, musical

Simon Critchley

ZEFA

Coty/Jerrican

***Many wood-exporting areas** of the world – such as Sri Lanka – operate without the benefit of power tools and computers. Cutting wood along its length (below) reveals its grain. The grain of a wood depends on the arrangement of its fibres and sap-conducting cells.*

DUTCH ELM DISEASE – SLOW TREE-KILLER

GSF Picture Library

Dutch elm disease is a fungus that causes a gradual withering of trees. In the 1970s it killed approximately 20 million of the 23 million elm trees in southern Engand alone. Fungal spores are transmitted from tree to tree by bark beetles that burrow under the tree bark leaving distinctive channels (left). There is no known cure for this disease but its spread can be checked in several ways. Controls can be exercised on imports and exports of wood and its products. Diseased consignments can be destroyed, fumigated or kiln-dried to kill the carrying beetles. Living trees with Dutch elm disease should be destroyed.

instruments, toys, kitchen utensils and ornaments. Railway sleepers, fence posts and poles for supporting telephone and electricity cables are also commonly made of wood.

Cosmetic work

Often a veneer (thin layer) is cut from an attractive piece of wood and glued to a base wood, to give an attractive finish to a piece of furniture. Sometimes a veneer is set into a shallow recess cut into the surface of a piece of furniture – a technique known as inlay. In another technique, known as marquetry, two or more veneers are used to create a pattern or picture.

Natural wood has limitations. The largest planks obtained from trees are seldom more than 25 cm wide, and wood is often flawed, with knots, cracks and lumps of resin. However, processing timber can produce strong boards a couple of metres wide. Nothing need be wasted. Even wood chips and shavings can be processed into chipboard and particle board.

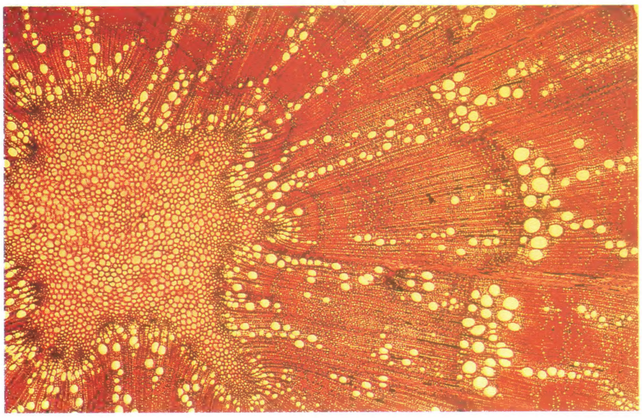
Plywood

Plywood is made up of several layers of rotary-cut veneer glued together. Knots are cut out and holes and slits are filled with wood or synthetic filler. The layers are arranged so that the grain directions of alternate sheets are at right angles to strengthen the finished board.

Deforestation

World demand for wood is growing. But supplies are not solely affected by the rate at which we cut down trees for timber. That rate can be controlled to some extent by replanting. Trees are also cut down and burnt to clear land for farming, and are being damaged by atmospheric pollution.

Acid rain is caused by the build-up of chemicals in the atmosphere from the burning of fossil fuels such as coal and oil. It was first identified over 100 years ago but its effects on forests only became apparent in the 1970s. The first symptom of damage is reduced growth followed by abnormal loss of foliage, distorted branching, mineral imbalance and increased vulnerability to frost, drought and pests. Only worldwide attempts to reduce drastically emissions of sulphur and nitrogen oxide can restore our atmosphere to its pre-industrialized state and safeguard the world's trees.



Sinclair Stammers/Science Photo Library

The dense heartwood *of an oak tree can be seen in this light micrograph. Rings of large and small cells are also visible. Each ring represents one year's growth.*

Marcelo Brodsky/Scinece Photo Library

An artificial wood pattern *is applied to hardboard using a type of printing press. The sheet of hardboard is attached to a drum and paint is transferred by pressure using rollers. Hardboard is made – like paper – from wood fibres.*

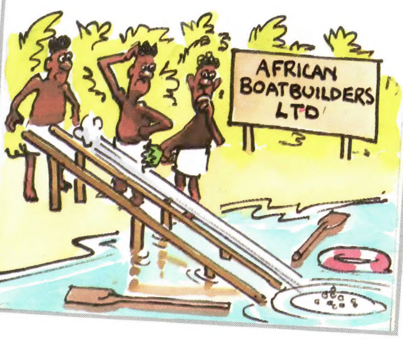
Ben Johnson/Science Photo Library

Planks and mouldings *are colour-coded for identification at a timber merchants after being cut, graded for quality and seasoned to remove sap.*

Just amazing!

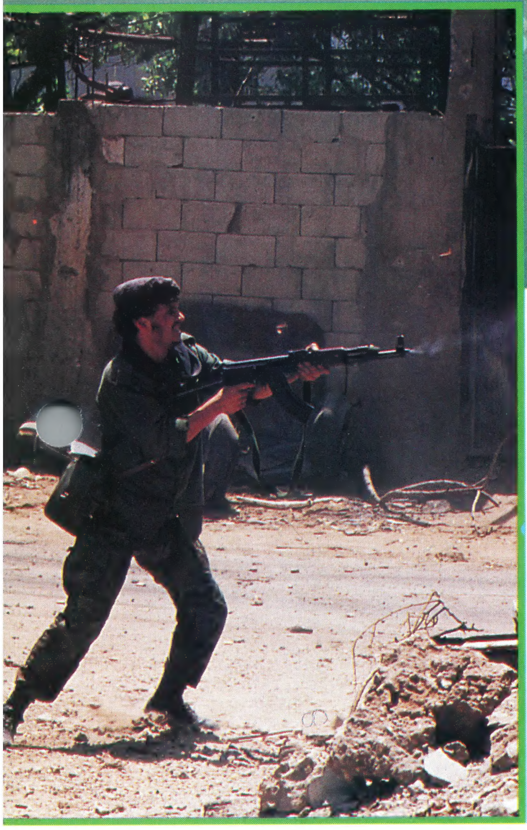
ANCHORS AWAY!

MOST WOOD FLOATS - BUT THE AFRICAN TIMBER BLACK IRONWOOD, WHICH IS 1.5 TIMES MORE DENSE THAN WATER, SINKS LIKE A STONE



Paul Raymonde

SIPA/Rex Features Ltd



Gamma/Frank Spooner Pictures

***War rages** in the streets of Beirut with Christian and Muslim militia battling from house to house. Armoured vehicles are vulnerable in narrow streets, while unsupported infantrymen (left) are more at risk in the wider boulevards.*

- 'HOUSE CLEARING'
- SNIPERS
- STRONGPOINTS

URBAN COMBAT

ALL MODERN ARMIES ARE trained to fight in urban areas. They learn both to attack and defend cities. The British Army has even constructed a special village in its Salisbury Plain training area where it can practise these techniques.

When attacking an enemy who is defending a city, it is sometimes possible to use the streets by avoiding open areas exposed to enemy fire. But often it is necessary to move down the gardens and backyards that run parallel to the streets, across the roofs of buildings, underground through the sewers or drains, or through the interiors of houses by 'mouseholing' through the dividing walls. Progress is slow, sometimes painfully slow, as the troops fight their way from house to house.

Street clearing and 'house clearing' require special skills. Fighting is at very close quarters with the enemy only a street or a house away. Sometimes he is only a room away on the other side of a wall. The infantryman has to be prepared for hand to hand combat. His reactions must be instantaneous – there are no second chances.

Enemy fire

One problem of fighting in the cities is the difficulty of locating the source of enemy fire. The crack of a high velocity rifle echoes and re-echoes off surrounding buildings so that it is virtually impossible to be sure where the round is coming from.

Urban warfare is sometimes further confused by the smoke and dust that hangs in the streets. Fields of fire and of observation are much more restricted than the infantryman is used to, although there is probably more and better cover than in a rural environment. Invariably, it is the attacker who must show himself in order to make progress.

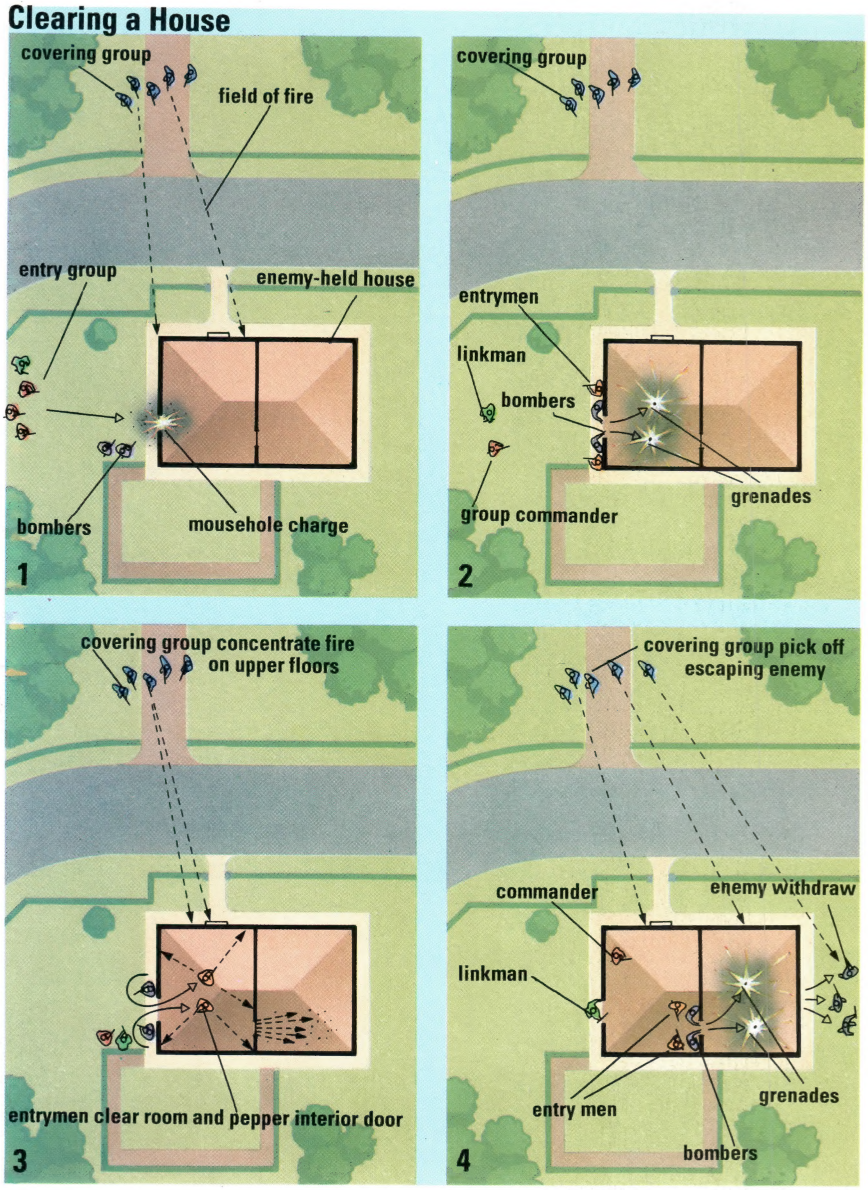
Snipers defending an urban stronghold can cause difficulties. They are usually so well hidden that it is difficult to get an aimed shot at them. The usual response is to fire an anti-tank weapon at the window or part of the house from which it appears the fire is coming – overkill perhaps, but this is very effective nonetheless.

Use of tanks

Tanks can provide very effective close support, but in a narrow street, they are very vulnerable. An anti-tank weapon can be fired into the side or rear of the tank at very close quarters.

There are, of course, other difficul-

Clearing a House



Paul Williams

Under covering fire, *the bombers place a mousehole charge (1) to flush out enemy forces. Grenades clear the first room (2). Entrymen shoot at concealed enemy 'mouseholes' (3) before moving on. The commander controls the timing, while the linkman relays orders to the covering group (4).*

ties of using tanks in places such as Northern Ireland where there are many ordinary citizens in the streets going about their everyday business. In this situation, a tank's massive firepower is far too indiscriminate to be used.

When defending a city, the business of fighting from building to building needs careful thought and a great deal of preparation. It is important that the right building is selected for a strongpoint. If it is too small, a single hit from an artillery shell or a direct hit from a tank could well kill everyone in the building. On the other hand, a building that is too large may mean the defenders are spread so thinly that they are unable to cover all the approaches or provide an adequate concentration of fire to prevent the enemy storming – and overrunning – the building.

Defending a house

As well as size, the type of construction is also important. Traditional three- or four-storey masonry houses with strong walls made of brick and stone are the best for defence.

Soldiers use various ways to strengthen a chosen strongpoint building. Sandbags can be piled against the walls. Cupboards or chests of drawers or even mattresses can be filled with earth and staircases and doorways barricaded.

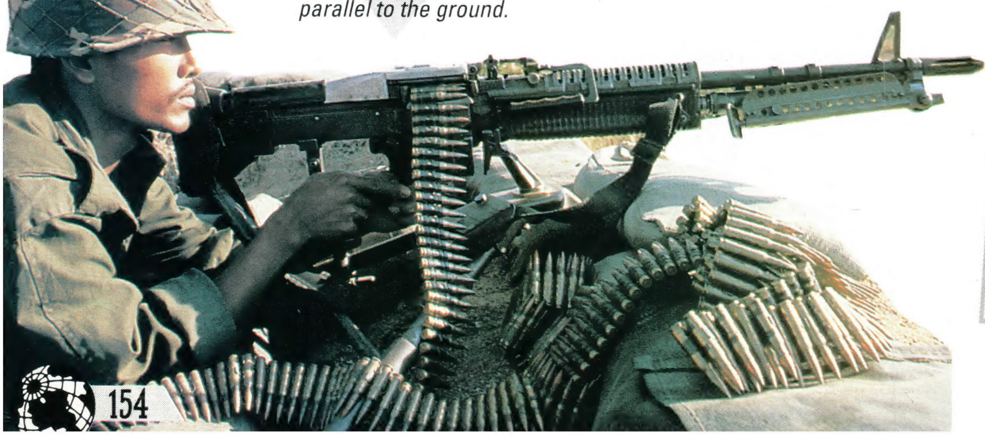
Shock of explosions

Movement around the building should be via holes in walls and ceiling by means of ladders, ropes or piled up furniture. Ceilings are prepared for the shock of explosions by shoring them up with strong timbers resting on a solid base and wedged against solid parts of the building.

The troops' next task is to site the weapons. Automatic weapons should be sited near ground level. A machine gun can cover a long zone if the rounds are travelling parallel to the ground. That way they can cut down both enemy troops nearby and those further away in a single sweep of the gun.

Siting snipers

Snipers, however, are better sited up where they can see further. A rifleman firing through a window should be as far back as possible so that he cannot be seen from the outside. Even better, he should construct a loophole underneath a window sill or through the tiles in a roof. Hand-held anti-tank weapons should be sited in upper storeys so they fire down on to the tops of armoured vehicles, which are less well protected.



Machine guns *are best sited low down. They control a longer area when their bullets fly parallel to the ground.*

SIPA/Rex Features Ltd

Just amazing!

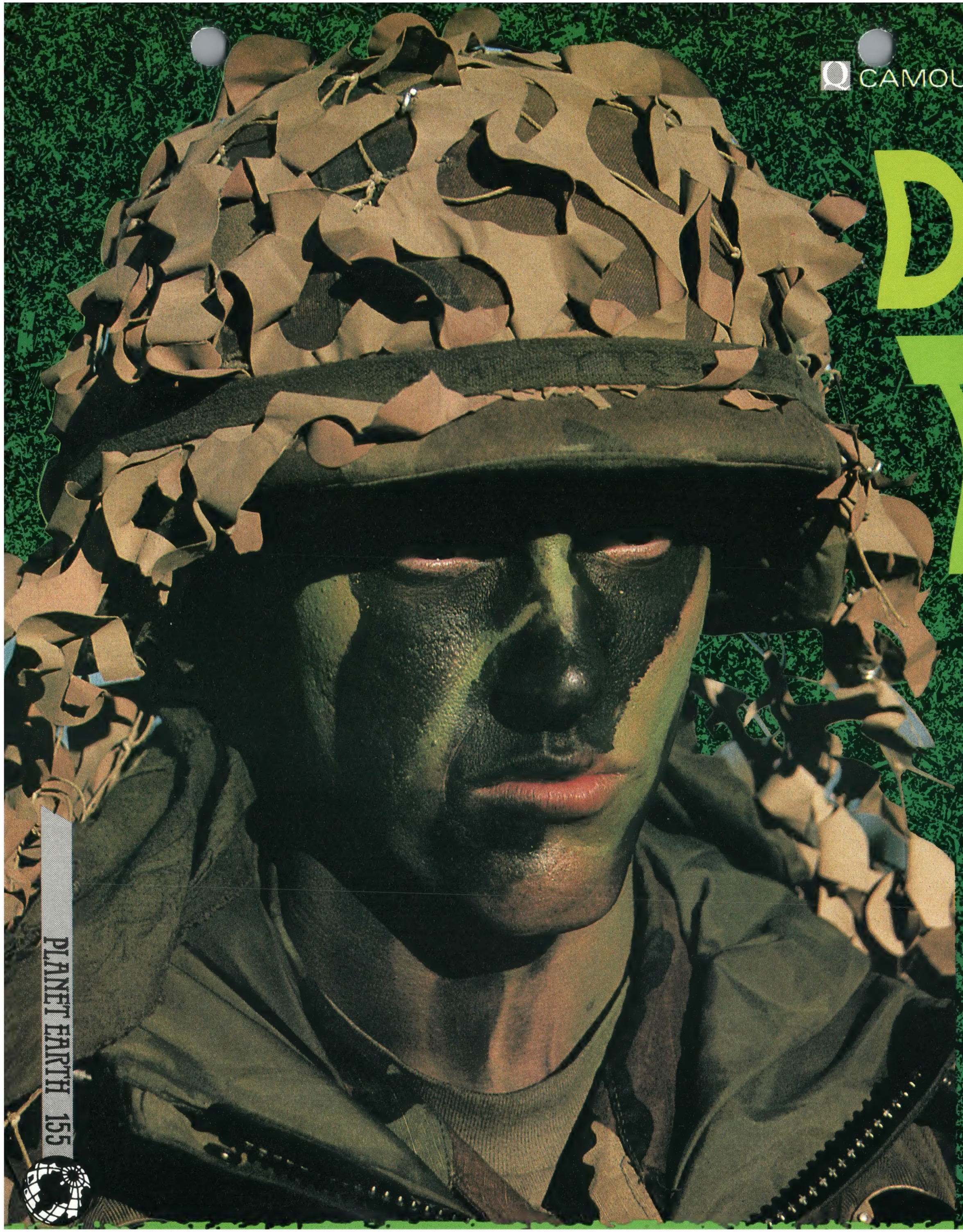
NEIGHBOURS

TECHNIQUES OF URBAN COMBAT HAVE BECOME SO SOPHISTICATED THAT IT IS NOT UNCOMMON FOR ATTACKERS AND DEFENDERS TO OCCUPY THE SAME HOUSE WITHOUT REALIZING THE OTHER IS THERE.

Paul Raymonde

CAMOUFLAGE CONCEALMENT CONFUSION

DECEPTION TECHNIQUES



E Nevill/TRH Pictures

Facial camouflage *matches skin colour to that of the surroundings and disguises the familiar shapes of the head, eyes, nose and mouth.*

AS MODERN SURVEILLANCE equipment becomes increasingly sophisticated, methods of concealment and deception on the battlefield are improving to cope.

The NATO definition of deception is 'those measures designed to mislead the enemy by manipulation, distortion or falsification of evidence designed to induce him to react in a manner prejudicial to his interests' – in other words to trick the enemy. The use of camouflage, of concealment, of dummies, decoys, feints, lures and other tricks are all forms of deception.

Camouflage is the simplest form of deception. It is designed to, at best, completely hide a person or object from the enemy or, if this is not possible, to confuse or mislead the enemy as to their exact location.

Camouflage can be applied to a person's skin in the form of camouflage cream, and can be worn in the form of disruptive pattern combat clothing. It is applied to vehicles and equipment as paint and camouflage netting. A great deal of research goes into the development of the most effective netting, paints and materials.

Camouflage netting

But it is not just on land that camouflage nets are used. Ships in harbour can also be camouflaged effectively. A ship is moved alongside a quay, preferably into a corner. A lightweight tubular framework is lifted aboard and erected. This framework straddles the space between the ship and the quay and is clad with camouflage netting so that, from the air, the ship looks like an extension of the quay.

Aeroplanes can be camouflaged, not only to merge with the ground when looked at from above, but also to merge with the sky. The camouflage consists of three shades of grey. Dummies and decoys are another means of deception. Dummy equipment is designed to make the enemy think you are somewhere you are not. Dummy equipment is simulated.

A decoy may or may not be the real thing. Its purpose is to attract the enemy's attention and, more particularly, his fire. It is often a dummy tank or an abandoned real tank.

Camouflage nets *are made with computer-generated colour patterns to match different terrains – thus guarding against visual detection. Thermal blankets can be used with these nets to trick thermal cameras.*

Diab-Barracuda

TRH Pictures

Diab-Barracuda

Radar nets *positioned over reflecting objects scatter most radar waves. A tank (left) seen through an infra-red camera is disguised by a net designed to reflect infra-red light in the same way as its surroundings.*

False tracks

A complete dummy position near an actual position can be made more realistic by, for instance, having a mess tin glint in the sun, by making vehicle tracks into and out of the position and by stationing one or two men there to provide signs of movement and occupation. If, at the same time, the actual position is concealed particularly well, the enemy may be encouraged to waste his fire on the wrong position and, when he attacks it, he may leave himself open to attack in the flank.

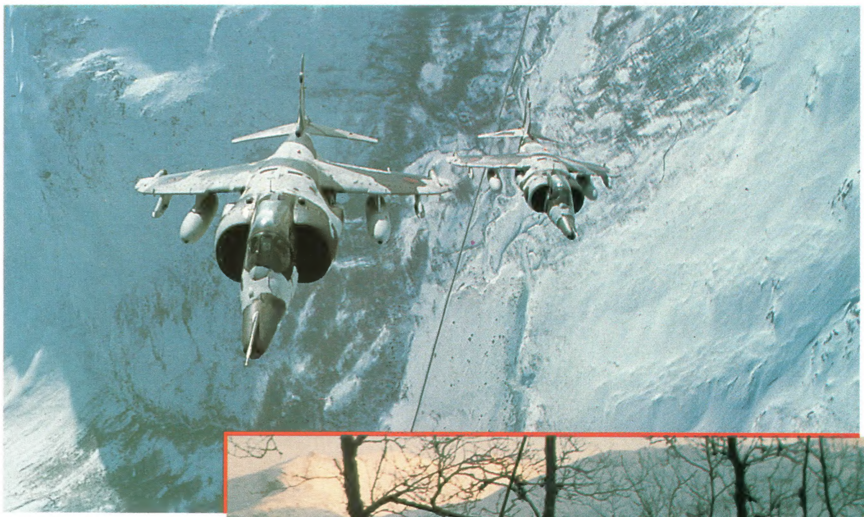
Bailey bridge decoy

Combat engineers often employ deception techniques. For instance, during an advance or withdrawal overland, an army depends to a very large extent on the bridges it has erected over rivers for its logistic support – assuming that permanent bridges have been destroyed. Also a large number of dummy missile positions can make it more difficult for enemy pilots to locate and eliminate the real ones.

Inflatable bridges and missile systems are made by a Swedish company called Diab-Barracuda. Their Bailey bridge can be erected by eight men in just one and a half hours. A 30-metre section weighs only 205 kg. Seen from the ground or air, even at close range, the bridge looks remarkably like the real thing.

Smokescreen

Smoke is another means of deceiving the enemy. Troops can advance or withdraw under its cover and it can be used to confuse and disorientate the enemy. It can be used on a grand scale over many miles or smoke can be produced in localized



US Navy/TRH Pictures

Richard Cooke

Concealment *is as important as camouflage. These men are careful not to 'sky line' – reveal their silhouettes by walking across the top of a hill. A British RAF Harrier Jet (above) in snow camouflage colours.*

areas with the 51 mm mortar or by using smoke grenades. If used correctly, smoke can deceive the enemy as to which way an attack is coming.

Dummy heat sources

It is also possible to deceive the enemy by creating false heat sources. Concentrations of men and equipment carefully hidden in woods can easily be detected by modern surveillance equipment – such as thermal imagers and Infra-red Linescan photography.

While it is difficult to counter these devices by reducing the heat signature of real vehicles, it is possible to confuse them by putting dummy heat sources, such as paraffin heaters, in woods where there are no troops.

DOD/TRH Pictures

TRH Pictures

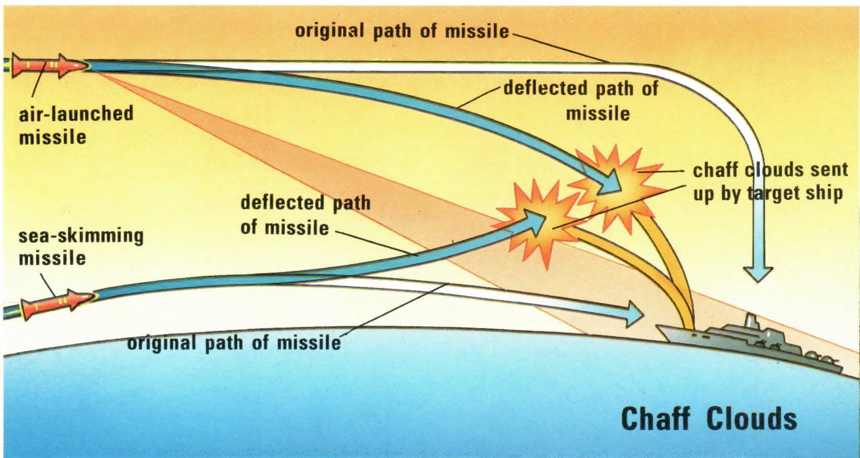
***Smoke** is used to disorientate the enemy, shield troop movements and for signalling. Smoke generators aboard amphibious craft (left) emit a dense white smokescreen to obscure their movements.*

Misinformation

Radars constantly survey the battlefield. By using anti-radar camouflage nets to hide real vehicles and by creating false echoes elsewhere, the enemy can very easily become confused.

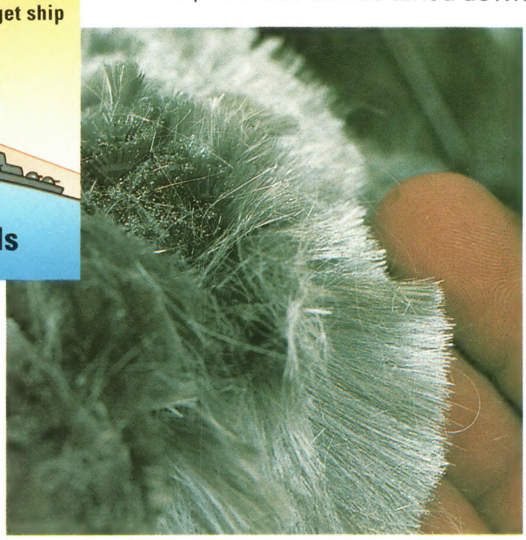
Radio traffic can also be used to simulate a non-existent formation of troops. Radio operators talking to each other about fictitious plans for an attack can fool the enemy. Even if a hoax is uncovered after a few days or a few hours, it may provide vital time for a successful attack to be mounted elsewhere. Similarly, false information may be provided over real radio nets in the hope that the enemy will be listening in.

Behind the front line there are a number of sizeable and static installations on which troops may depend for support – whether it be an airfield, a missile site or a supply depot. Even if the enemy knows where these are, they can be concealed or disguised.



Joe Lawrence

***Naval chaff rockets,** shot from a ship deck, carry chaff 1,000 metres into the air to lure anti-ship missiles. In the case of a sea-skimming missile, chaff may be launched while a ship is still below the missile's radar horizon. Chaff (right) – tiny aluminium-coated glass fibres.*



Tracor Aerospace Inc

Foam

Parallel aprons and dummy aircraft can be created on airfields to mislead pilots of attacking aircraft. Coloured foam (which lasts for several days) can be used to remove key indicators such as road junctions, perimeter tracks, and runways to confuse pilots.

Air attack

It is necessary for the pilot of a modern jet to spot his target from a distance of 4 km if his attack is to be successful. At 4-km range, flying less than 50 metres above the ground and closing at 920 km/h the pilot will catch sight of perhaps the perimeter fence and track, roads and other paved surfaces, the pattern of buildings, equipment in the open and prominent landmarks near the base. Much can be done to 'tone-down' all these tell-tale signs.

The perimeter can be toned down

TVI Corporation

The principal problem facing designers of modern decoys is to make them effective enough to fool an enemy's sophisticated sensors, without becoming so complex that they are not cost-effective.

The life-size M1 Tank decoy (top left), developed for the US Army, can be erected in five minutes by two men. Disassembled, it weighs only 23 gm and can be carried by a soldier in a duffle bag. This decoy comprises a four-colour printed canvas skin stretched over a collapsible aluminium frame. The 'tank' is designed to appear three-dimensional when viewed from a distance. Seen through binoculars the effect is even more convincing. Different configurations are available so that 'tanks' appear to the viewer front-on, from an angle, and semi-hidden in a ditch (right – decoy viewed from 100 metres). A heating element and a 1 kW gas generator to fool thermal sensors complete the system.

TVI Corporation

The F-16 Fighting Falcon decoy (below) can be assembled in one hour by four men. It weighs just 730 kg and measures 14.76 metres in length, 9.2 metres in width and 5 metres in height. Plane decoys can be complimented with radar reflection and thermal signatures to make them more effective.

Close up, the F-16 decoy would fool no one. But it is designed to be seen on the runway, by a pilot in the air travelling at high speed. The decoy is sufficiently realistic at a range of 300

Diab-Barracuda

metres to distract a tactical attack pilot (a pilot looking for single targets). Travelling at a speed of 835 km/h and at a height of 50 metres, concentrating upon mulitple cockpit and weapons systems tasks, a pilot is worried about surface to air missiles and other anti-aircraft fire and has little time to analyse targets. At 250 metres he will have committed himself to expending some of his warload harmlessly on the decoy. As he makes his attack exit, he may just realize that he has risked his life and an expensive aeroplane to attack a fabric model. But by then it may well be too late to make a second approach on a real target.

Jo Lloyd

***The British Army** use exercises to show that expectations affect what we perceive. In each of these phrases the article – 'the' or 'a' – is printed twice.*

by having the same type of ground either side of it; for instance if there is a ploughed field outside the perimeter then the ground inside will also be ploughed.

Anonymity

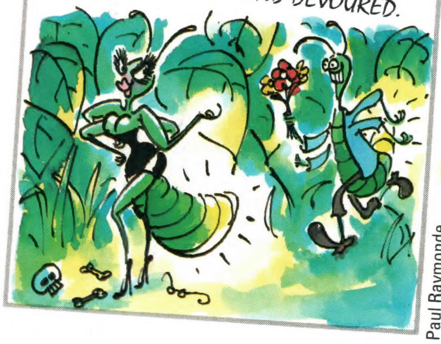
Trees can be planted to break the outline of buildings and to hide access roads. If roads cannot be hidden they might be made to appear part of the civil system. False roofs can be put on a large flat-roofed building to make it look like a row of houses.

Although deception to some extent involves pure cunning it is also a science, and technology plays a vital role. As the threat of war recedes, deception technology may well provide some cost-effective alternatives.

Just amazing!

REAL MANEATER!

FEMALE PHOTURIS PENNSYLVANICA FIREFLIES LURE MALES OF OTHER SPECIES BY MIMICKING THEIR MATES' RECOGNITION SIGNALS. RESPONDING MALES ARE CAUGHT AND DEVOURED.



Paul Raymonde

GREATEST SHOWS ON EARTH

ZEFA

Mount Tolbachik, *on Kamchatka Peninsula in the far north-east of the former USSR, erupted in July 1975. Lava flowed from the volcano at a rate of 165 metres per second.*

THOUSANDS FLOCK TO SEE wonders of nature such as Niagara Falls in North America. Other spectacles – eclipses of the Moon and Sun, for instance – can only be seen from time to time and some are unforgettable, once-in-a-lifetime experiences.

Many of the most awe-inspiring natural displays occur in the sky. In the Arctic and Antarctic regions, the sky is often covered with patterns of shifting, glowing, coloured lights. The 'polar lights' are known as aurora borealis in the northern hemisphere and aurora australis in the southern hemisphere. They are caused when electrically charged particles from the Sun, trapped in the Earth's magnetic field, collide with atoms in the atmosphere above the North and South Poles.

Eclipses of the Sun

Unlike aurorae, which are hard to predict, the timing of eclipses of the Moon and the Sun can be calculated years in advance, from their predicted orbits. Total solar eclipses, in which the Moon passes exactly in front of the Sun, are the rarest and most fascinating kind. The track of such an eclipse – the area over which the Moon casts its full shadow, or *umbra* – may be only a few hundred kilometres wide and the eclipse never lasts for more than eight minutes. Even so, enthusiasts travel to remote locations such as Antarctica for a glimpse of the event.

This is the only time that the Sun's faintly glowing outer atmosphere – its *corona* – can be clearly seen without the use of any special equipment. The amount of light reaching us from the Sun is reduced to 1/800th of its normal level. The temperature drops as it would at night, stars can be seen in the sky and the light is similar to that on the night of a full moon.

Eclipses of the Sun

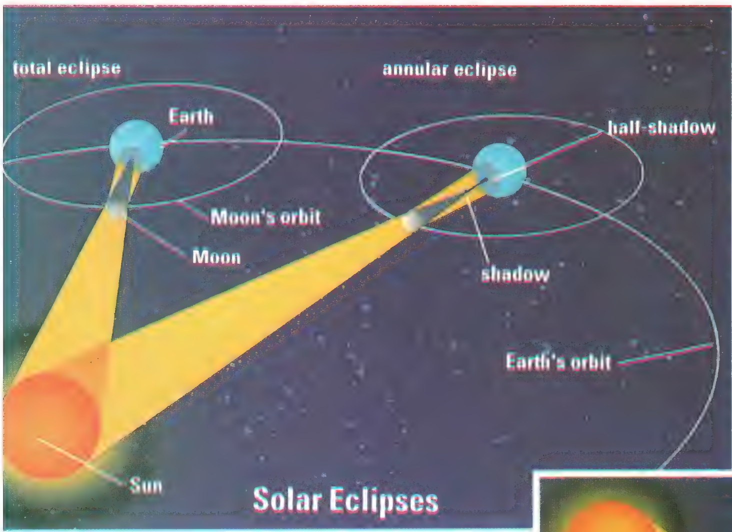
Another astronomical show is put on by meteor showers. When the Earth, on its yearly journey around the Sun, cuts across the orbit of a comet, swarms of dust particles that have escaped from the comet hurtle into the Earth's atmosphere and burn up in a series of brilliant flashes. The brightest of these showers of 'shooting stars' are called the *Perseids* and fall each August, being brightest on the night of the 12th.

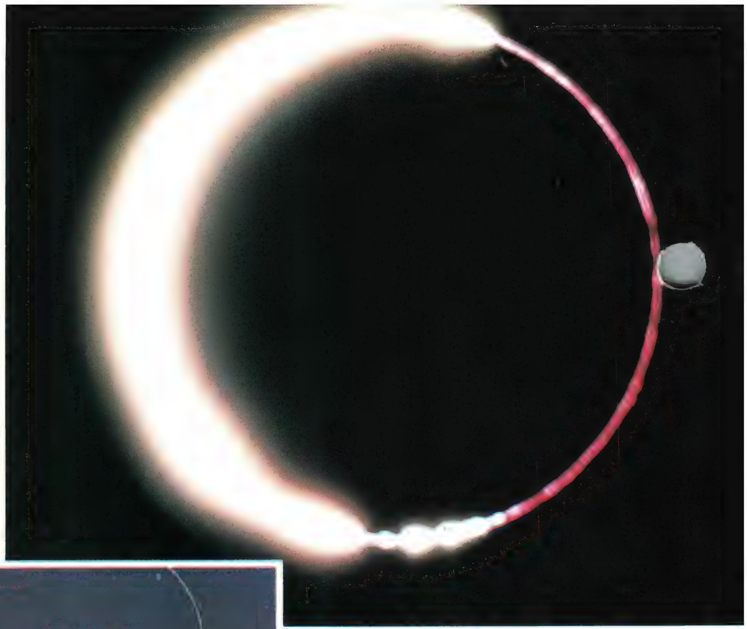
Occasionally, large meteors, weighin several kilograammes or more, do noturn up completely. These glowing, white-hot fire balls speed through the atmosphere at up to 20,000 km/h. Many shatter on impact, but some remain intact and blast a hole in the ground.

Ronald Royer/Science Photo Library

Millions saw Halley''s Comet *(here some 60 million km above California) in early 1986, when its orbit took it close tooEarth for the first time since 1910.*

One such incident happened in Arizona, USA, where Meteor Crater, a depression 1.2 km across and 180





Dr Fred Espenak/Science Photo Library

Mark Franklin

***Solar eclipses** occur when the Moon passes between the Sun and the Earth, blocking the Sun's rays – partially, as in the case of this annular (ringlike) eclipse in 1984 in North Carolina, USA, or totally. In a lunar eclipse (left), the Earth passes between the Sun and the Moon, casting a shadow over the Moon and effectively obscuring it.*

WONDERS OF SPACE

Earth's greatest natural wonders are dwarfed by those on other planets in our Solar System. On Mars, a volcano called Olympus Mons is some 26 km high – almost three times the height of Mount Everest. Another Martian feature, Valleris Marineris, is a canyon eleven times the length and four times the depth of the Grand Canyon in North America. Weather systems too are on a gigantic scale. The Great Red Spot on Jupiter is a swirling storm with a diameter twice that of the planet Earth's.

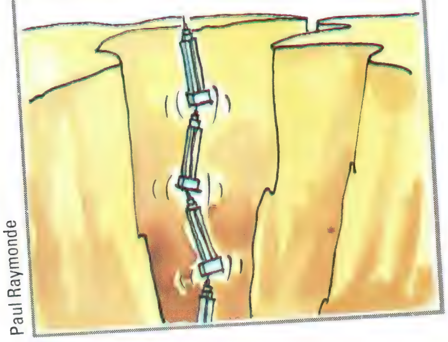
metres deep, was blasted out of the ground by a meterorite some 25 metres in diameter and 63,500 tonnes in weight that fell to Earth at some point between 2,000 and 50,000 years ago. It is estimated that once every 50 million years or so there occurs a collision between the Earth and an asteroid (a minor planet), which might be comparable in size to a mountain.

Waterfalls are one of the natural world's most breathtaking sights. Angel Falls in Venezuela is the tallest waterfall in the world. It plunges 979 metres from the Auyan Tepui plateau ('Devils Mountain'). In terms of water volume, the Victoria Falls in Zaire ranks first, with a flow rate of 17,000 cubic metres per second.

Just amazing!

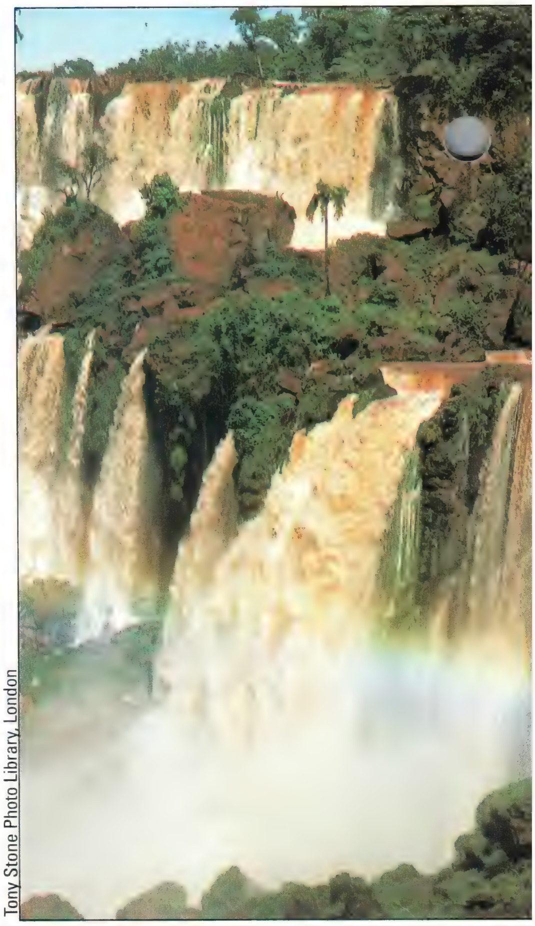
WAY ON DOWN

THE GRAND CANYON IN ARIZONA (USA), CARVED OUT BY THE COLORADO RIVER OVER TEN MILLION YEARS, IS DEEP ENOUGH TO BURY FOUR EMPIRE STATE BUILDINGS ON TOP OF EACH OTHER.



Paul Raymonde

***The Iguazu Falls** on the border between Brazil and Argentina. Over 270 cascades, some dropping as much as 82 metres, plunge off the Parana plateau into the gorge below.*



Tony Stone Photo Library, London

Gigantic waves

Another amazing water spectacle is a river bore – a single, fast-moving wave that surges up river from the sea at high tide. About 60 are known. The largest of these tidal waves occurs on the Hang-chou-fe river in eastern China. At spring tides, the wave reaches a height of 7.5 metres and a speed of 27 km/h. Its approach can be heard 22 km upstream.

Among the most popular tourist attractions in the world is a geyser – Old Faithful in Yellowstone National Park, USA. Water heated underground to near-boiling point shoots as high as 40 metres into the air.

Deadly eruption

In other parts of the world, molten rock itself may rise to the surface. Spectacular from a distance, a volcanic eruption may be deadly at close range. On 18th May 1980, the top 400 metres of Mount St Helens in Washington, USA, was ripped away in a massive explosion that left 34 people dead.

Visitors to the Hawaiian Islands, in the Pacific, see displays of less violent volcanic events. These include rivers of orange-glowing lava that flow down mountainsides at speeds of up to 40km/h and even lakes of lava left behind after a series of eruptions. One lake, in Kilauea Iki Crater on the island of Kilauea, is filled to a depth of 120 metres with molten rock heated to over 1000°C.

In Malaysia, *in 1988, a firework display lasted for 9 hours 27 minutes with over three million firecrackers on a display 5,723 metres long.*

Q GUNPOWDER Q ROCKETS Q HUGE DISPLAYS

FIREWORKS!

FIREWORKS' DAZZLING colours, sparkles, whooshes, and bangs are caused by a variety of chemical reactions taking place at high temperature. And those high temperatures are caused by one important substance – gunpowder.

Gunpowder was invented in the 9th Century AD by the Chinese who used it to make firecrackers and rockets for special occasions. Later, its explosive power was harnessed in guns and cannons.

Gunpowder is a mixture of saltpetre, carbon and sulphur. At a fireworks factory, the carbon, in the form of charcoal, is ground together with the sulphur in a ball mill. This is a rotating drum with metal balls inside, which thoroughly crush and mix the carbon and sulphur to form a blackish powder.

Gunpowder

The carbon-sulphur mix is then added to the saltpetre in a wooden drum mixer that contains wooden grinding balls. The resulting gunpowder is ground to an even finer, more compacted blend that is suitable for use in all types of fireworks.

When gunpowder is exposed to a flame or lighted fuse, the chemical energy stored in the mixture is released. The oxygen in the saltpetre reacts with the sulphur and carbon to produce large amounts of hot sulphur dioxide and carbon dioxide gas, which expand rapidly. At the same time, the high temperature produced makes the reaction spread quickly through the rest of the mixture, causing an explosion.

The skill in making good fireworks is to control that explosion so that it can produce spectacular effects that are still safe.

Exhaust gasses

In a rocket, for example, the gunpowder is packed inside a tough case which forces the rapidly expanding hot gases through a hole in the base. As the exhaust gasses escape at high pressure, they push

ZEFA

The technology *used to make fireworks is over a thousand years old. Gunpowder and the chemicals that produce the colours and sparks are packed into cardboard tubes. But simple firework rockets are the forerunner of those that put the Shuttle into space.*

The World of Interiors

SOLID FUEL BOOSTERS

A large number of unmanned spacecraft and missiles are launched using rockets propelled by solid fuel, that are just like huge fireworks.

These large rockets, however, carry a much more potent blend of chemicals than gunpowder to give them a very powerful thrust. Britain's nuclear submarine-launched Polaris missiles, for example, are propelled by a mixture of ammonium perchlorate and polyurethane fuel.

Solid boosters also help to accelerate the American Space Shuttle. Their main drawback is that, once ignited, they cannot be controlled like a liquid fuel rocket and so cannot be used in steering 'thrusters'.

the rocket's head and drive it into the sky. A stick attached to the side helps to stabilize the rocket in flight and helps in launching.

In a Catherine wheel, the gunpowder is packed into a long paper package. This is flattened through a mangle, then wound on to a wooden spindle. A nail driven through a hole in the middle of the spindle into a post holds the firework in place and the gases produced by the burning gunpowder spin the Catherine wheel around at high speed.

But gunpowder alone cannot produce the many spectacular effects of modern fireworks. These result from reactions involving other chemicals that are added at the factory.

Standard Fireworks Ltd

PE Parker

Burning metals

The reds, whites, yellows, and greens come from burning chemicals that contain certain metals. Barium salts, for example, give off a greenish light, while those containing strontium burn a vivid, bright red.

Long slow burning fireworks, *called 'lances', are used to spell out words or draw pictures against the night sky. They are nailed to wooden frames with their fuses linked in series.*

The most difficult firework colour to produce is blue. Recently, manufacturers have begun to use powdered PVC (polyvinyl chloride)to create a fairly bright bluish light.

The brilliant sparks given off by many fireworks result from burning powdered metals, especially iron and aluminium. Larger particles – filings – of these metals give the appearance of glitter, shining brighter and longer.

Stars and sparks

To produce a variety of effects in the same firework, manufacturers pack together a number of different chemicals. Mixed in with the gunpowder are so-called 'stars'. These are pellets made up of layers of various metals and metal compounds. As the shells burn through from the outside, different colours and sparks unfold.

The exact mixture of gunpowder with other chemicals, how much it is compressed and the way it is enclosed all determine the rate of burning. Roman candles, for example, have a slow-burning composition.

Small fireworks have a paper fuse impregnated with a slow-burning chemical. Major displays involving hundreds of large fireworks are started with electronic ignition systems so that they can be ignited from a safe distance. These displays are set up on metal gantries. Fuses join up the sets of fireworks.

But never forget, fireworks are DANGEROUS!

Huge explosions *and showers of sparks in the sky are produced by a 10-cm shell launched from a simple pipe mortar.*

Just amazing!

THE BIG BANG

AT A FIREWORK DISPLAY IN HOKKAIDO, JAPAN, ON 15 JULY 1988, A 700-KG SHELL CALLED UNIVERSE I PART II WAS LET OFF. IT BURST INTO A SHOWER OF SPARKS 1200 METRES IN DIAMETER.

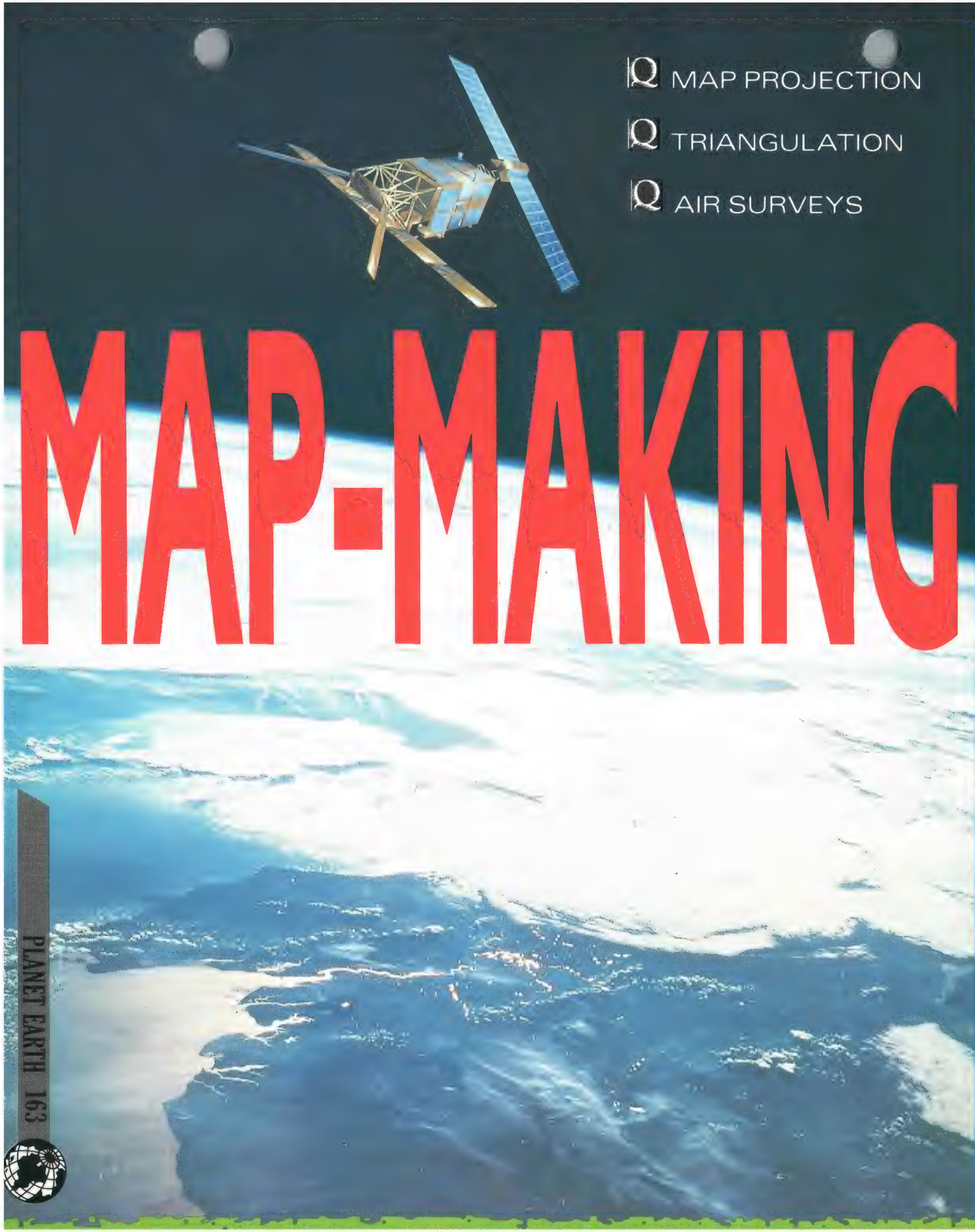
Paul Raymonde

MAP-MAKING

Q MAP PROJECTION

Q TRIANGULATION

Q AIR SURVEYS



European Space Agency/SPL

Earth Satellite Corporation/SPL

***Satellites** are used to ma[p] remote regi[on]s (far left) w[here] inaccessible ... makes ...ntional ...ing methods ...sible. Sa[telli]te pictures of citi[es] (left) are also used [t]o compile street maps.*

MANY PEOPLE – MISTAKENLY – believe that maps are like aerial photos of a piece of land taken on a cloudless day, with all the things shown in the right place. But because the earth is a sphere it cannot be accurately represented on a flat surface. Cartographers (mapmakers) therefore have to distort or exaggerate certain features.

Imagine that the map is first drawn on an extremely thin rubber skin that coats a geographer's globe. How could you remove this rubber skin and lay it flat on a piece of paper?

One way is to make a pinprick at the south pole, then stretch the skin until it can be removed. Then the piece of rubber is stretched to make a flat disc. This shows the whole Earth in one circular area, but with this system (the so-called Azimuthal projection) the south pole becomes the circular perimeter of the disc.

Cylindrical projection

Another, very familiar projection is named after Mercator, a 16th century geographer. Imagine the globe is now

translucent with a light bulb inside it. A long sheet of paper wrapped around the globe, touches it at the equator. An image of the features of the globe is projected on to the paper. Tracing these features produce a map that closely resembles Mercator's projection. But now, distances become enormously exaggerated the further you go towards the poles, making Greenland, for example, look bigger than Australia, when it is actually less than a third of the size.

The great advantage of the Mercator projection is that directions are accurately shown. A journey made in a constant direction – say, 17 degrees east of north – appears as a straight line on the Mercator projection. In most other projections a line of constant direction over the globe is generally represented by a curve on the map, making an air or marine navigator's job extremely difficult.

Distortion

Some distortions in maps are not forced on the mapmaker by geometry; they are introduced deliberately to make the maps more useful.

Railway passengers, for example, are not much interested in true distances and directions – they mainly want to know at which stations a particular train stops and where they

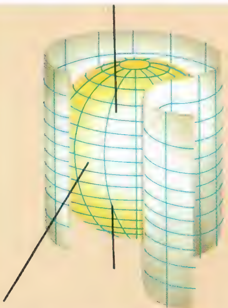
MERIDIANS

Any place on the Earth's surface can be given its own unique label by means of its co-ordinates. Lines of longitude are circles called meridians, running from the north to the south pole, dividing the globe into 360 degrees. The zero line is called the prime meridian and runs through Greenwich, in south-east London, UK. The east-west position of any place is measured as so many degrees, minutes and seconds east or west of the prime meridian.

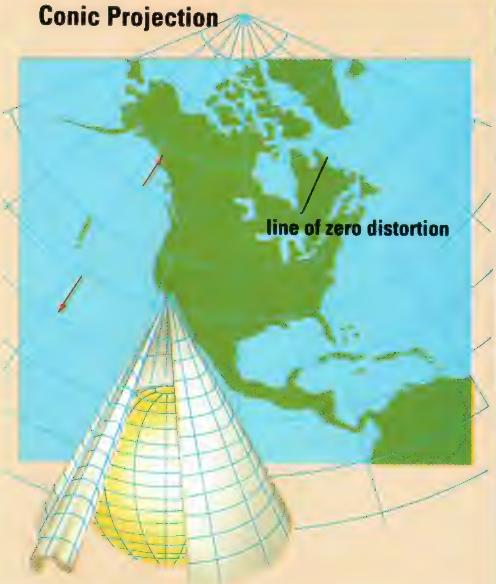
North-south distances are measured in relation to the equator, the circle that runs around the globe halfway between the poles. Parallels of latitude are circles drawn around the Earth parallel to the equator, between the equator and the poles. Thus San Francisco's position is described as 37°45′ N, 122°30′ W. Sydney is 33°50′ S, 151°10′ E.

Wild Leitz

***Air survey cameras** are held in mounts that are designed to reduce vibration and allow the cameras to be rotated to compensate for aircraft drift. caused by air currents.*



Cylindrical Projection



Conic Projection

***Spherical maps** – or globes – are impractical for large-scale use, so map-makers have to portray the Earth's surface by means of various 'projections'. Cylindrical projection from the Earth's centre on to a cylinder touching the equator is widely used. Conic projections are best suited to middle latitudes.*

Mapping Techniques

Azimuthal Projection

Geco/Science Photo Library

***Surveyors** use a theodolite to measure horizontal and vertical angles between the control points of the area to be mapped.*

have to change trains. The map of the London Underground is a good example. Originally, the map was geographically accurate – depicting the different stations at the correct distances and showing the shapes in the lines. As the railway system expanded, however, the map became so convoluted (it was dubbed the 'vermicelli' map) that passengers had great difficulty reading it. On the modern map, the shapes of lines are simplified and their directions are not accurate. The widely spaced stations of the outer regions are shown as equally spaced. Motorway maps and maps of air routes often use similar simplifications.

Rubber-sheet geometry

Such a map is described as 'topologically equivalent', which means that it depicts information by stretching and squeezing as necessary, but without tearing. Topology is often called 'rubber-sheet geometry'. Distances and directions are altered, but the important relationships – for example, that a certain railway line runs through certain stations in a certain order – are unchanged.

Symbols

A map's final appearance depends upon its function. At the planning stage the mapmakers will meet to discuss how best to interpret the results of the surveyor's work. Decisions are made regarding symbols – such as whether roads will be shown using two fine lines or one thick one. Colour-coding is also important. Each colour on a map is used in conjunction with lines and symbols to convey a wide range of information.

Scale

The scale of the map will be another important consideration, because this dictates the geographical coverage and the quantity of information depicted. For example, a map of the USA at a scale of 1:1,000,000 (1 cm on the map represents 1,000,000 cm or 10 km on the ground) could only depict large towns, major roads, rivers and large geographical features. But a map of California at a scale of 1: 200,000 (1 cm on the map represents 2 km on the ground) could show the complete road system, including minor roads, rivers and streams and small physical features.

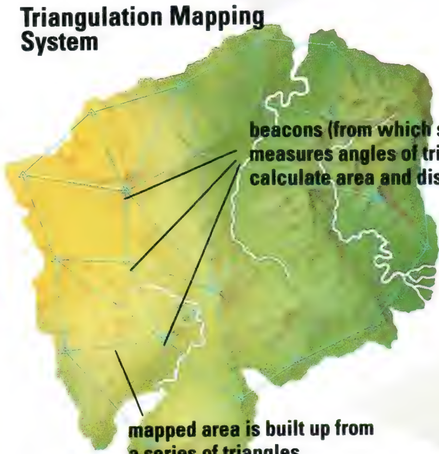
Punch registration

After the planning has been completed the first 'rough' has to be compiled. This is done with coloured inks and brings together all of the information on one plastic sheet. To achieve the perfect alignment of detail a technique called 'punch registration ' is used. Plastic sheets up to a maximum size of 100 x 150 cm have a series of holes punched down one side in much the same manner as a roll of film. Steel pins are then inserted into the holes allowing other plastic sheets to be accurately placed on top of the original sheet. As these plastic sheets are translucent, detail can be added to the top sheet and still register with the one underneath. The sheets can be separated and replaced as many times as necessary and as long as the pins are re-inserted, registration will be exact.

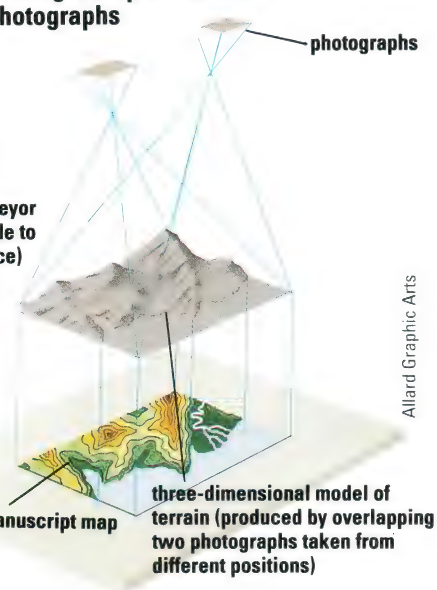
The colours on a map are not all drawn on the same plastic sheet or 'foil'. There can be as many 24 com-

***Large areas are mapped** by dividing the terrain into triangles and measuring the angles with a theodolite. Aerial photography provides the data for ordnance (Government) survey maps.*

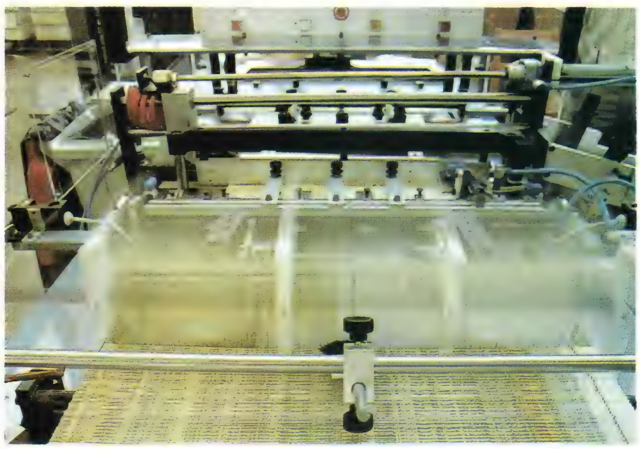
Triangulation Mapping System



Making a Map from Aerial Photographs



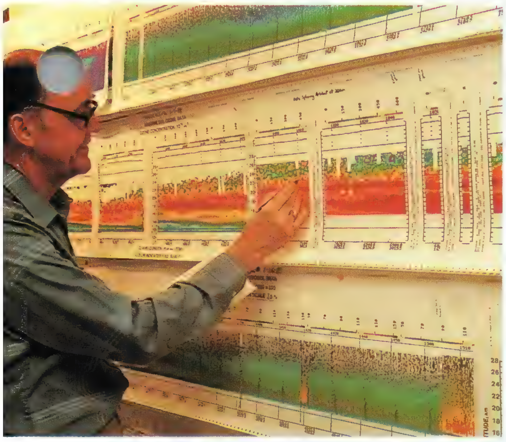
Allard Graphic Arts



Ordnance Survey

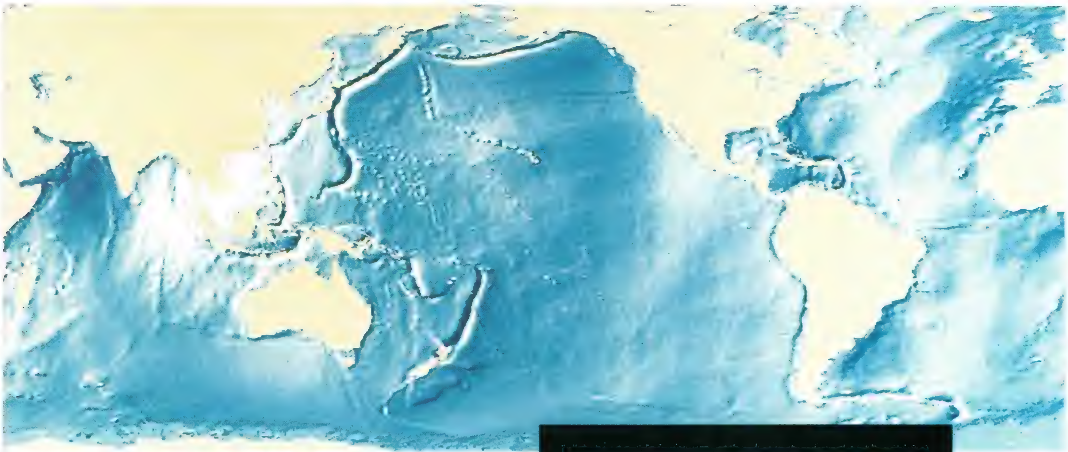
A map-folding machine – the final stage in map production. Maps are produced manually, on lithographic printing machines, or digitally – by feeding the data into a computer.

MAPPING THE SKIES



NASA/Science Photo Library

NASA scientists have used the latest laser technology to produce images of the 'holes' in the Earth's ozone layer. Data gathered over the Arctic by a DC-8 flying laboratory and high altitude ER-2 flights have shown a marked increase in chemicals known to destroy ozone. In Antarctica, satellite data has revealed a hole that has been growing in size and severity since 1980.



NASA/Science Photo Library

***Satellite pictures** of the ocean floor reveal higher mountains and deeper valleys than those found on dry land. The 1,325 km-long Philippine Trench in the West Pacific can be clearly seen in in this computer image of the sea bed. The 1500-metre-high volcano (below left) was mapped by side-scan sonar. It was discovered in the East Pacific at a depth of 4,000 metres.*

Institute of Oceanographic Sciences/SPL

ponent foils combined together photographically to produce the four final films from which the colours will be printed.

Mapmakers get their basic information by surveying – on the Earth's surface, from the air or from space. On the ground, the co-ordinates of stations are found by triangulation (the measurement of angles using

ORIENTEERING

Rod Organ/Sporting Images

Orienteering is a sport that tests the participant's map-reading skills. Competitors navigate their way at their own pace between features marked on a special coloured map. An orienteering course varies in length from about 2 km, with six to ten control points for beginners and children, to over 12 km for experienced orienteers. The winner is the person with the fastest time.

theodolites) or trilateration (the measurement of distances using electronic instruments).

The best-mapped countries are covered with a dense network of reference points, known as beacons or trigonometrical stations. 'Bench marks' engraved in stone or metal are reference points whose heights above sea level have been precisely measured using accurate instruments called levels.

Aerial photography

To find out the exact location of landmarks such as buildings, woods and fields, aerial surveying is by far the most rapid and comprehensive method. An aircraft criss-crosses the chosen terrain. On board is a special camera, weighing perhaps 200 kg and producing large negatives, perhaps 23 cm square. It points straight downwards and takes photographs spaced at regular intervals, as controlled by the aircraft's speed.

Stereoscope

Overlapping photographs are taken, so that every point on the ground appears on at least two pictures. Two consecutive pictures can be viewed in a machine called a stereoscope, which gives a three-dimensional view of the relief – the rise and fall of the ground. This enables the mapmakers to work out the relief and mark it on the map.

Infra-red cameras

Essentially the same thing is done over larger areas by satellites orbiting a few hundred kilometres above the Earth. The world's remotest and most inaccessible places can be rapidly mapped in this way. Infra-red cameras can show the health of vegetation and the temperature of the sea; they can also chart the development of hurricanes, oil spills, and food crops.

Relief maps

In addition to showing the position of towns and countries, maps can provide information on height and depth. Height above sea level and depth below it can be shown by means of colour. Or a striking impression of the relief of the terrain can be given by shading it as if it were illuminated from a low angle. Relief and additional details such as buildings may also be represented pictorially.

Contour lines were first invented to show heights. A contour line joins points on the ground that are at the same height, but can also be used to show other types of information at a glance – about climate, population density and so on.

The future

Maps can now be made from computers, in which the data is revised daily by surveyors who feed in digitized map amendments. Moving maps, using Global Positioning Systems, may soon enable car drivers to locate their position from satellites and follow their route on a moving map.

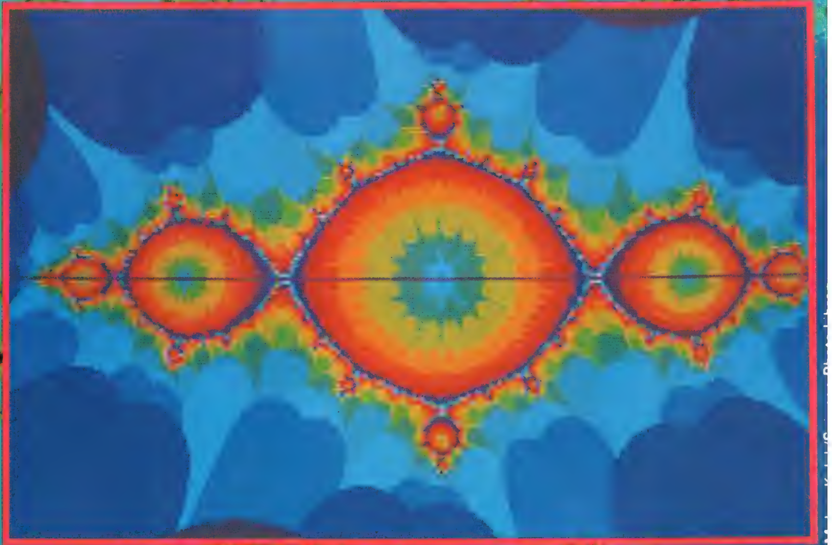
Just amazing!

COUNTRIES IN COLOUR

IT TOOK 120 YEARS TO PROVE THAT ONLY FOUR COLOURS ARE REQUIRED TO SHADE ANY MAP SO THAT EVERY ADJACENT AREA HAS A DIFFERENT COLOUR.

Paul Raymonde

PATTERNS OF CHAOS



FINDING ORDER IN THE WORLD and explanations for complex processes has been the traditional role of scientists. Now they are being challenged with the discovery of chaos, often in what they had thought were the most orderly systems.

Man has long been of the opinion that explanations for strange and inexplicable phenomena are just around the corner; that as science progresses the mysterious will become clear. The discovery of chaos has caused a revolution in the world of science.

Chance

Now, rather than continuing to fill in the blanks, scientists are having to rethink some long-established concepts. Because instead of chance being an anomaly in an otherwise orderly world, the theory of chaos suggests that chance is fundamental in the Universe. Perhaps chaos can explain, for example, why, while ocean tides rise and fall against the world's shores in an unchanging cycle, waves slap against the hull of a moored ship with an irregular beat.

Not all processes behave chaotically. But scientists are realizing that most kinds of processes do – and perhaps the most important ones.

Deterministic laws

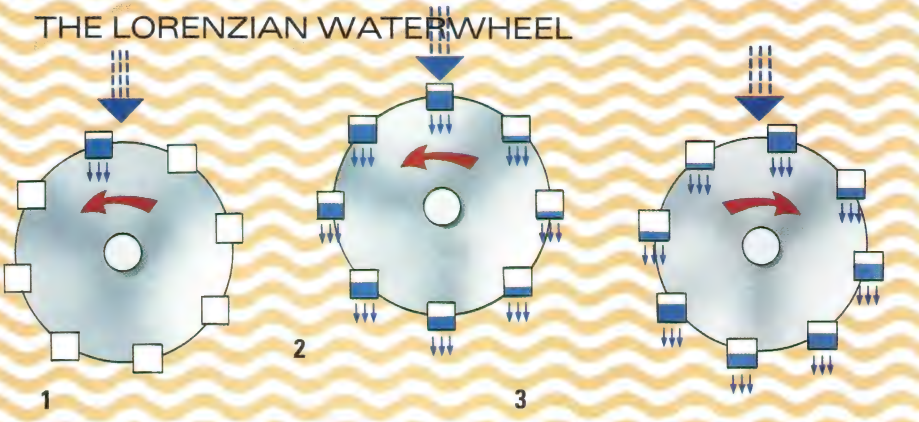
A process that can be explained precisely by known laws of physics is called deterministic. Kicking a football or stricking a billiard ball, for example, produces measurable and

***The Mandelbrot set** is a fractal (irregular and fragmented shape), details of which can be graphically represented on computer by plotting complex number co-ordinates. Strange attractors (above) are another feature of fractal geometry.*

Dr Fred Espenak/Science Photo Library

THE LORENZIAN WATERWHEEL

The simple waterwheel *demonstrates a chaotic system: 1) Water pours steadily into the top bucket and its weight starts the wheel turning 2) The waterwheel rotates at a steady rate 3) As water input is increased the wheel spins faster. Each bucket receives less water and full buckets start on the upward climb before having time to empty. Thus the wheel slows down and reverses its spin. The wheel then spins and reverses itself randomly (chaotically).*



James Gleick/Mark Franklin

predictable results. The object's motion at each and every moment is determined by its position and motion at the instant before.

Pendular motion

The new discoveries in chaos theory show that even deterministic systems can be unpredictable – the swing of a pendulum for example. The first accurate clocks relied on the regularity and predictability of a pendulum's motion. But even a pendulum not subject to chance disturbances can behave wildly – 'chaotically'.

This does not happen with a pendulum making small swings in a grandfather clock. But suppose a motor drives an arm that pushes the pendulum rod gently at a precisely controlled number of pushes per minute. When the driving rate is very close to the pendulum's rate of swing, the pendulum's motion builds up and becomes large. It is when the motion is large that it can become chaotic.

Sensitive dependence

First the pendulum swings to and fro in a straight line. Then it may begin to trace out an ellipse – a flattened circle. The ellipse may get fatter while the direction of swing changes. Then it may get smaller while staying the same shape. There may be times when the pendulum swings in a straight line again and times when it will suddenly and unpredictably change its direction of rotation.

If the experiment is repeated from the beginning a totally different sequence will be obtained. Yet the laws that the pendulum is obeying are very simple. The varying results are caused by very slight differences in the starting conditions from one experiment to the next – slight differences in position or in the pushes delivered by the motor. These differences are far too slight to be measurable and yet they can alter the end result dramatically. This phenomenon in the theory of chaos is dubbed 'sensitive dependence on initial conditions'.

Population studies *of animals, birds and insects reveal the existence of chaos in ecology. The deterministic influences of the environment, such as food supply, predators and disease, do not account fully for fluctuations in population density.*

Owen Newman/Oxford Scientific Films

Population trends

But chaos is not confined to physics. Ecologists use it to explain the fluctuations in density of animal populations. A simple model of population affected by deterministic laws assumes that the greater the density of population, the greater the number of births. Thus if a population doubles, the number of births doubles and if a population trebles, the number of births trebles, and so on.

With this simplified model, if birth rates are too low, the population will die out. If the birth rate is increased the population will grow, fast at first and then more slowly, until it reaches a fixed value. Chaos emerges when the birth rate is pushed higher still. Then the population increases to a certain value, falls to a lower one, then grows to the previous value, then decreases again – flipping back and forward between the two values. If the ratio of births to deaths goes even higher the population level becomes completely chaotic. It jumps between high, low and intermediate levels –

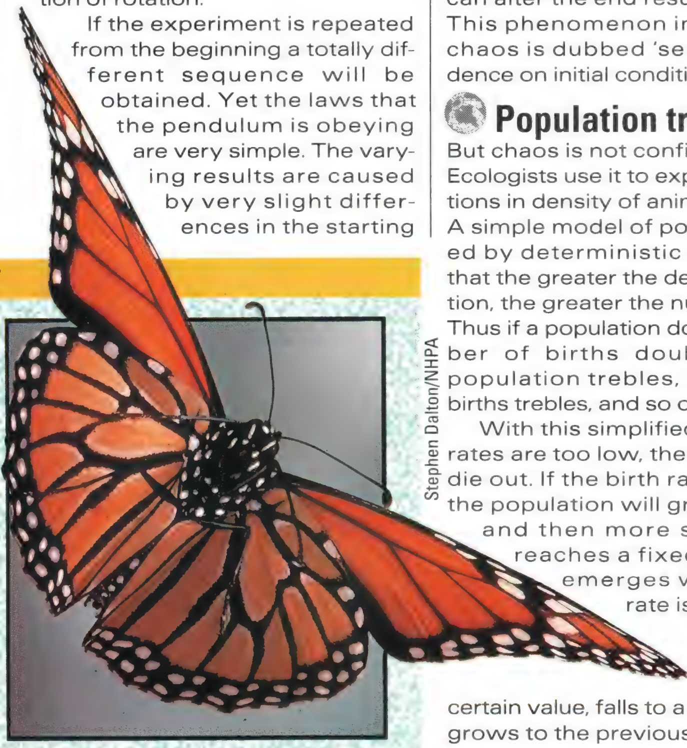
THE BUTTERFLY EFFECT

In 1960 Edward Lorenz, research meteorologist at the Massachusetts Institute of Technology, was trying to forecast weather behaviour using a computer.

Lorenz was trying to speed up the computer's working by 'rounding off' his figures – writing .452 instead of .452311 for example. He had assumed that this tiny modification could have little effect on his results. In fact, Lorenz discovered it altered the results greatly.

Lorenz found that minute differences in initial conditions – temperatures, pressures or wind directions – can have dramatic knock-on effects. This 'sensitive dependence on initial conditions' means that whenever weather is chaotically affected, long-range weather forecasting will be unreliable.

This phenomena has been called the butterfly effect because it suggests a butterfly beating its wings in Brazil today could cause a hurricane in Paris next month. The butterfly effect has come to epitomise chaos theory.



Stephen Dalton/NHPA

with no pattern appearing and no final equilibrium being reached. In this example chaotic variations could be due to, and affected by, perfectly deterministic processes governed by simple fixed laws.

A chaotic process that may be less dependent on deterministic laws is shown in a study of the measles epidemic among schoolchildren. As expected the infectious disease spreads more rapidly when children return to school after a summer break. Also as expected, the epidemic is shown to be checked by programmes of innoculation.

Chaotic infection

But despite these deterministic trends, the number of children that develop measles from one year to the next follows a somewhat chaotic pattern. If in one year many children develop measles, the following year tends to have very few cases. After an average year, follows a year of a similar number of cases. And after a year of very few measles cases even a general trend is difficult to predict.

Repeated patterns

In nature chaotic processes often create patterns. Viewed from a satellite, the hills and mountains of Earth form a rough pattern. Standing on a mountainside, you will see rough terrain with humps and boulders. Looking at a boulder under a microscope, the surface will appear rough and mountainous. A far more powerful electron microscope will reveal another mountainous terrain on a still smaller scale.

Repeated patterns also appear commonly in branching forms. Tree trunks, for example, become branches that become twigs. On the twigs the pattern is taken up by the leaves. Thick veins on leaves branch into smaller veins that branch into yet smaller veins. The spreading out of the tree 'body' in this way helps the leaves capture more sunlight and gives the tree stability against the wind. Thus branching is fundamental to the life of the tree.

Branching forms

Branching is used also in the design of the human body. Blood, for example, is carried very effectively to and from all parts of the body by a branching system of blood vessels in ever-decreasing sizes. A small cut anywhere on the skin surface will cause bleeding, and yet the blood and vessels make up only about five per cent of the body's mass.

Another comparison can be made with the intricate branching of windpipes in the lungs. The body's ability to absorb oxygen is proportional to the surface area of the lungs. The surface area of an adult human's lungs – if they could be laid out on a flat surface – would cover an area greater than that of a tennis court.

Heart flutterings

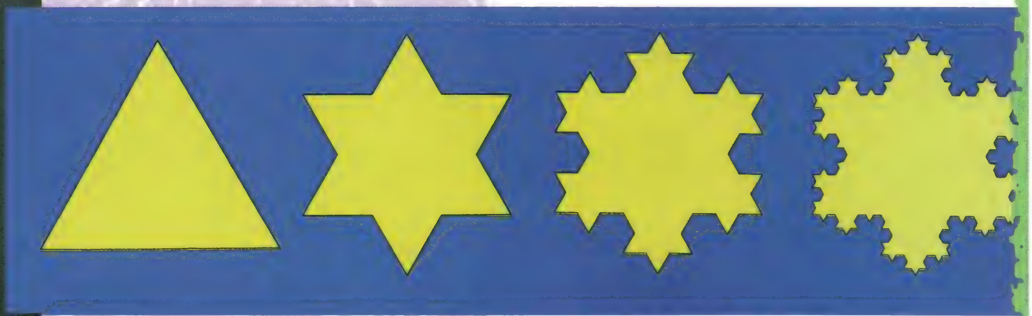
Chaotic behaviour, as well as structure, is being found within the human body. It has long been assumed that a steady heartbeat is a sign of health and that fluctuations are a sign of illness. But closer study shows that in healthy bodies, heart rates vary continuously and chaotically. Although the average adult pulse rate may be, say, 60 beats per minute, this can change by as much as 20 beats per minute in just a few seconds. In the hours or days before a heart attack, the pulse rate of a patient

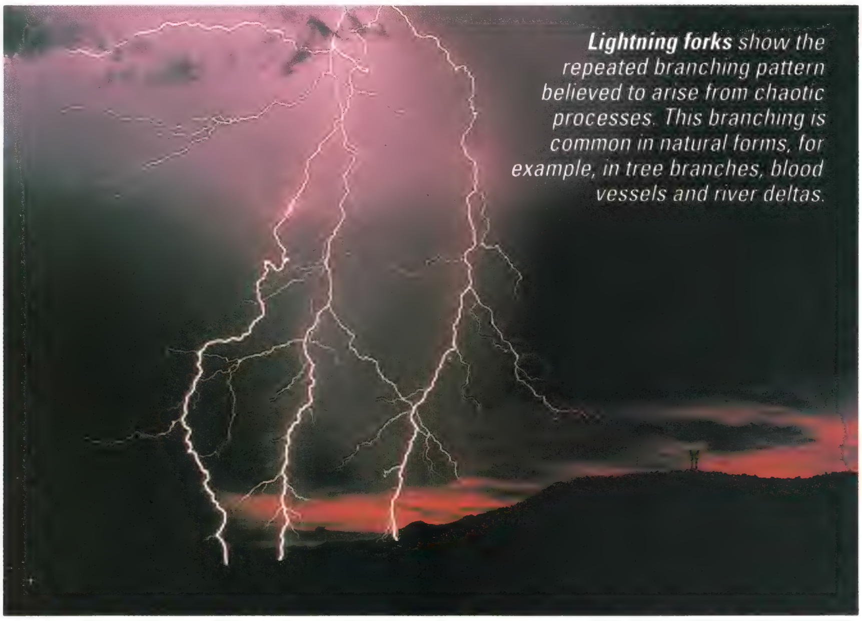
AN IDEAL SNOWFLAKE

The Koch 'snowflake' was first described by Swedish mathematician Helge von Koch in 1904. The core shape is an equilateral triangle. On the middle third of each side, another triangle is added – one third the size of the original. The process is repeated for the new triangles. The resultant shape looks like a snowflake. Theoretically it is possible to continue adding triangles indefinitely. Interestingly, while the outline of the Koch snowflake is infinite, its area remains less than the area of a circle drawn around the core triangle.

Snow crystals (left) are made up of water molecules arranged with two hydrogen atoms at an angle of 105° to one oxygen atom. The fixed shape of this molecule means that a stable crystal forms only when arranged as a six-branched figure. Despite this hexagonal symmetry each snowflake is unique. Because their growth is influenced by so many factors, conditions are never identical for two snowflakes.

Sauer/ZEFA





Lightning forks show the repeated branching pattern believed to arise from chaotic processes. This branching is common in natural forms, for example, in tree branches, blood vessels and river deltas.

Tony Stone Photo Library, London

PROFILE

TERMS

Chaos	the mathematical science of unpredictability
Fractal geometry	the study of irregular and fragmented shapes
Mandelbrot set	the most complex and important fractal discovered to date
Strange attractors	points around which chaotic systems revolve

Chaotic chemical changes *in this shallow dish show as circular waves radiating from point sources of an unknown nature (possibly dust particles). The waves cancel each other out on collision. Although the waves travel at a uniform rate of several mm per minute, the patterns that they make are unpredictable.*

Dr Arthur Winfree/SPL

may, paradoxically, become steadier.

Surges of electrical activity in the nervous system often seem to be chaotic. So do the levels of hormones – chemical 'messengers' that are released into the bloodstream to control bodily processes.

Fractals

Branching and other repeated patterns are believed to arise from chaotic processes. They can be modelled in two-dimensions on computer by mathematical curves called fractals. The Koch snowflake is one example.

One advantage of modelling fractals on computer is that their detail can be magnified indefinitely. A smaller fraction of a form can always be found beyond the one on screen. If you zoom in on any part of a fractal curve, the detail looks just the same as it does on the larger scale. Some fractals show wild, beautiful patterns, in which the eye cannot gain a resting place – every point breaks up into more complexity, and more detail beckons just beyond the visible.

Determining whether a system is chaotic, means finding the shape of its 'strange attractor'. Strange or chaotic attractors are a feature of fractal geometry. They exist in three-dimensional space but, like fractals, can be represented graphically by computer.

The Mandelbrot set

The images first produced by the mathematician Benoit Mandelbrot in 1979 are especially spectacular. They are an example of wildly swirling patterns produced by a computer from simple fixed rules – of chaos emerging from order. The Mandelbrot set is the most complex fractal discovered to date. Like other fractals it is created on computer using complex number co-ordinates.

A number is described as complex when it is made up of two parts – one real and the other imaginary. The important thing about the Mandelbrot set is that in magnifications of its detail, representations of the original image can be found. This self-similarity offers scientists hope of finding order within chaos and an understanding of fractal geometry.

Fern leaves *are programmed by nature to grow in a certain way. Leaf shapes can also be produced by computer with a random number generator choosing the co-ordinates. The randomness in such an exercise suggests that nature's own laws are chaotic as well as deterministic.*

Claude Nuridsany & Marie Perennou/SPL

CATASTROPHE

Gamma/Frank Spooner Pictures

The theory of catastrophe describes systems that undergo abrupt changes as a result of smooth alterations to their situations.

Using mathematical models, the theory describes, for example, the point at which water boils, stock markets crash and buildings collapse. Catastrophe theory has been used to describe and even to predict the outbreak of a riot in a crowd of people. It is concerned with less complex systems than the theory of chaos.

Just amazing!

DOUBLE-UP

IF YOU COULD PUT ONE GRAIN OF RICE ON THE FIRST SQUARE OF A CHESSBOARD, TWO GRAINS ON THE SECOND, FOUR ON THE THIRD ETC. THE END WEIGHT WOULD BE GREATER THAN THE ANNUAL WORLD RICE PRODUCTION.

Paul Raymonde

SPEEDING THE PLOUGH

MECHANIZATION HAS marched on the farm, continuing to speed operations and increase yields in every area of production from ploughing the field to milling the grain.

Most modern farm tools are powered by tractor. These are the power houses of agriculture. Today's tractors have a cab that resembles the cockpit of a small plane. They are sound-proofed and air-conditioned so that the driver can work long hours without fatigue. The air vents are filtered so that the cab is dust-free. The windscreen is tinted, the driver's seat as comfortable as any armchair and the steering column fully adjustable – it is both telescopic and tiltable.

Shuttle transmission

Many new tractors have computer displays, giving the driver instant monitoring of all the working parts and hydraulic systems. Brakes and clutch are self-adjusting to minimize the maintenance time that would keep this vital farm tool out of use. And the gearbox – which often boasts as many as 18 forward gears and nine reverse gears – has special systems like a shuttle transmission to make it easier to operate. This allows the driver to switch quickly back and forth between a forward gear and a reverse.

The new generation of

***The modern combine harvester** is more than a cutting and threshing machine. It is a grain factory on wheels that has brought computer technology into the wheat fields.*

Alex Bartel/Science Photo Library

tractors pull – and power – a range of modern ploughs, harrows and seed-drills. Almost all have been updated to meet the need of modern, mechanized farming.

Reversible ploughs

The age-old plough – a simple twisted blade dragged through the soil – has been modernized to a highly efficient tool. Modern ploughs can cut up to seven furrows at a time, using two sets of blades that can be reversed hydraulically so the farmer can plough either way up and down the field.

Some ploughs have rotating discs between the blades which help break up heavy soils like clay. Old-style ploughs would simply turn over a single long cut, leaving the earth in solid clods, while the new rotating-disc ploughs are designed to fragment the soil in several furrows, making cultivation both easier and quicker.

Powered harrows

Some modern harrows – the tools that further break up the soil ready for planting – are powered too. Knife blades, 30 cm long, are twisted as they are pulled through the soil and a roller covered with blades follows behind to help crumble the soil. Other modern harrows use the old disc system, where disc blades simply rotate as they are dragged across the soil. But modern disc harrows use two rows of discs – one smooth, one serrated – at an angle to each other, which churns the soil more efficiently. This type of harrow is also used for burying weeds and other waste, levelling land and thoroughly mixing chemicals into the soil.

Today's seed-drills have an array of small blades to cut through the soil and drop or blow seeds into the furrow. At the back of the drill unit is a comb harrow that brushes the soil back over the seed. However, a new type of seed drill has just been developed. This uses an arrangement of 38-cm diameter wheels which have radially extendible 'dibbers'. The seeds are fed out to the edge of the wheel and the dibbers extend to make a hole and place the seed precisely at the right planting depth.

Giant gantries

Currently, these farm tools are all pulled and powered by tractors, but the tractor itself could be on its way out. Despite their wide wheels, tractors still compact the ground where they drive and they destroy crops under their wheel tracks. So types of gantries, like those already used in horticulture, are now making their appearance in farmers' fields.

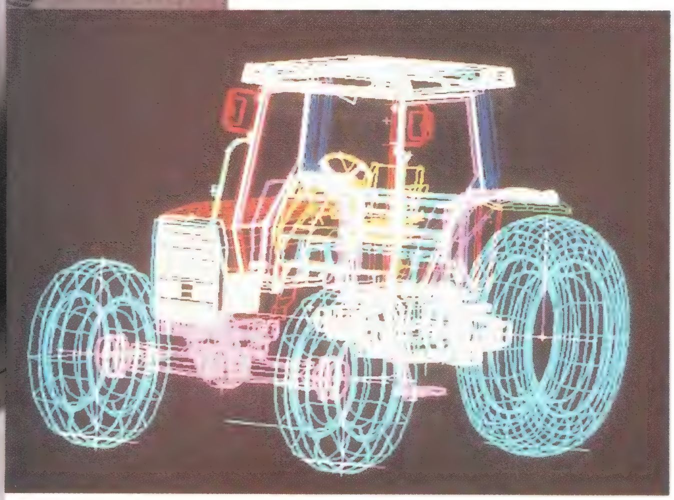
Gantries are incredibly wide machines – 12 to 15 metres from side to side – with a driver's cab on one end. Between the two sets of wheels on either end runs a long framework of struts and girders about 2 metres off

J I Case

Massey-Ferguson

The power house *of the farm is the tractor. Inside (above) the emphasis is on comfort and ease of control.*

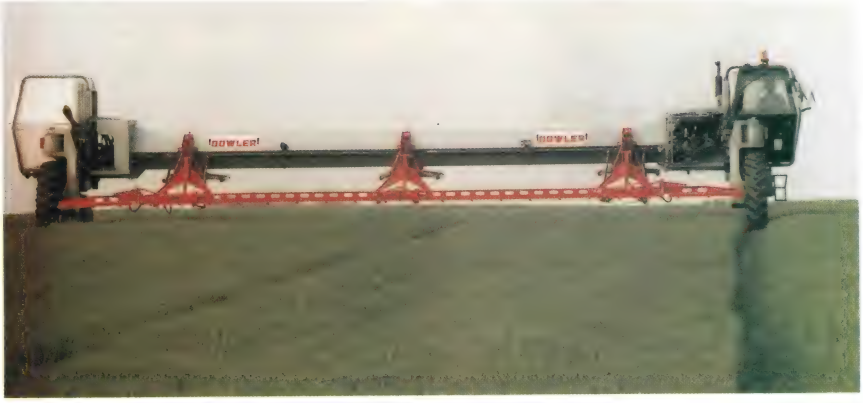
Massey-Ferguson



Massey-Ferguson

A tractor *rolling off the assembly line is the product of a huge amount of hi-tech engineering. This begins on the screens of the computer-aided design systems (below). Every detail is worked out on screen (below right) before a prototype is built.*

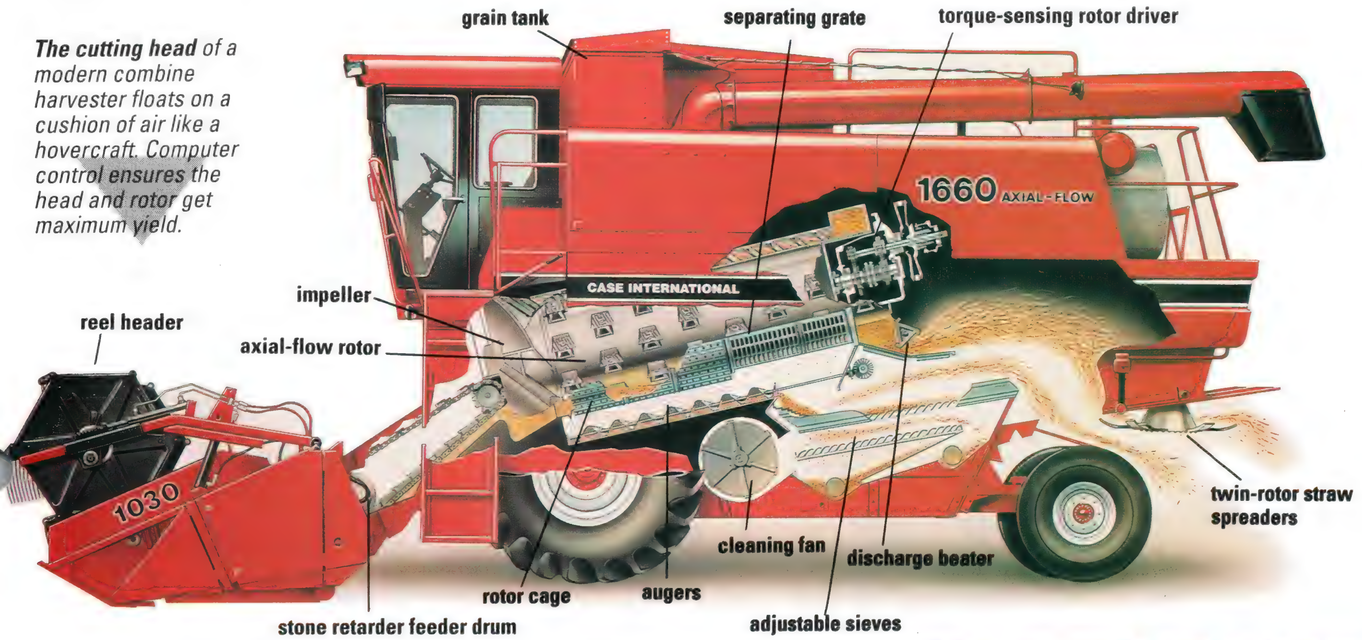
Massey-Ferguson



Dowler Gantry Systems

***A gantry** runs up and down the same tracks in a field, to minimize the amount of crop wasted under tractor tyres.*

the ground. Ploughs, seed-drills, harrows and other tools are suspended underneath the gantry. The advantage of using a gantry system is that only the narrow strip of soil where the wheels run is compacted and, if the gantry is run up and down in the same tracks every time it is used, only a very small proportion of the field is lost to cultivation.



***The cutting head** of a modern combine harvester floats on a cushion of air like a hovercraft. Computer control ensures the head and rotor get maximum yield.*

J I Case

Combine harvesters

The giant of the fields, the combine harvester, is like a tractor with the agricultural tools – a cutter and a thresher – built in. A computer controls the major functions. All the driver has to do is tell the computer what type of cereal it is harvesting and the harvester does the rest.

The cutter head is hydraulically controlled so that it stays a constant level above the ground. On hilly areas, a self-levelling system is used, which floats the cutter on a cushion of air in front of the harvester like a hovercraft. The air flow is controlled by the on-board computer to keep the cutting blades at the optimum height for each crop. The cut cereal is then drawn up a conveyor belt into the body of the machine where it is threshed.

Threshing cylinders

The thresher is a cylinder, usually mounted across the path of the straw conveyor. Ridges on the cylinder tear the grain from the straw. The grain pours down through a wire sieve under the thresher. The straw is passed on and tipped out of the back of the harvester to dry on the field until it is ready for baling.

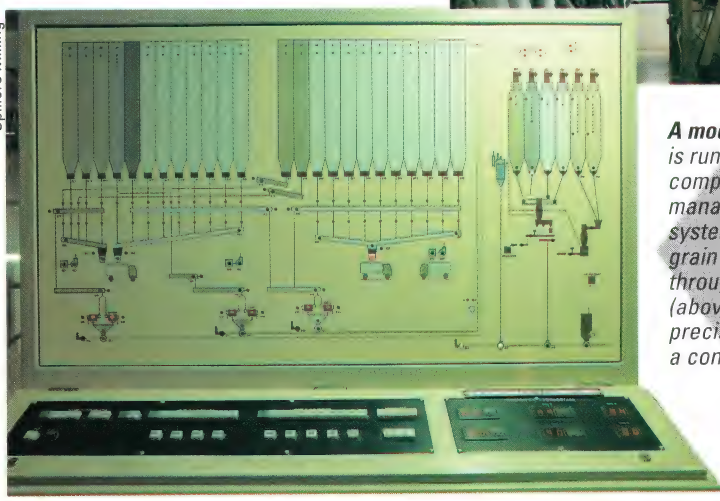
Newer combine harvesters have the threshing drum along the path of the straw. Instead of ridges, the cylinder has raised bumps on it. These run in a spiral and drag the straw through the thresher. Again, the separate grain falls down through a wire mesh, while the straw is tipped out of the back.

The grain goes on through another series of sieves and cleaners to move the last of the unwanted chaff, dust and straw. Eventually, it ends up in a grain tank at the bottom of the harvester. Then, when a trailer is brought up alongside, it is pumped out of a long pipe that sticks out of the side of the harvester. This way the grain can be removed without stopping the combine harvester.

Computing yields

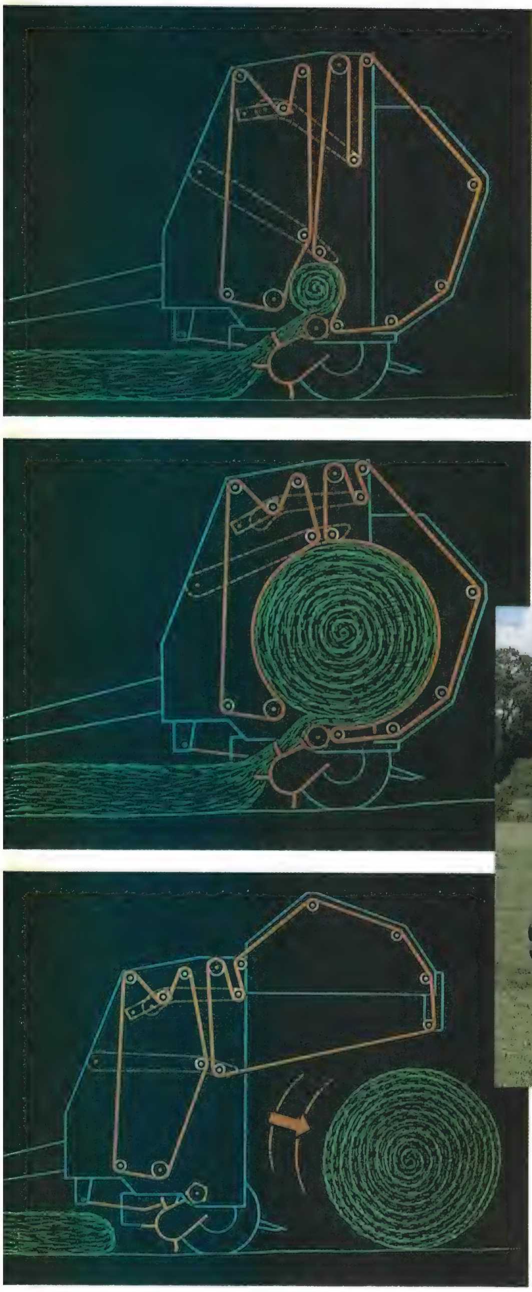
The on-board computer will display the drum speed, the grain loss, the cutting height and details of the yield so that the operator can adjust the speed of the harvester, the height of

Spillers Milling



Spillers Milling

***A modern flour mill** is run by a computer management system. Different grain is channelled through pipes (above) and mixed precisely to ensure a consistent output.*



the cutting heads and the rate of rotation of the thresher if necessary. The computer stores typical yield details for various crops, so the yield of any field can be instantly compared. The computer also monitors the performance of the combine harvester's engine, its fuel and coolant levels, fan speed and the level of the grain tank.

Grain stripping

A quicker alternative is now being developed though. It is called grain stripping. Instead of cutting the cereal before threshing the grain, it simply threshes the grain on the stalk and leaves the straw behind standing in the field. Later it can be ploughed back into the soil, burned off or cut and baled if the straw is needed.

But straw is bulky and storing it is a problem. One solution now under study is straw 'wafering'. The straw is cut and drawn up a conveyor belt to two interlocking cog wheels. These dice and compact the straw into small high-density straw wafers. Wafered straw can be used as bedding or for fuel just like regular straw, though it is only half the bulk.

The last – and biggest – machine used in the business of handling grain is the flour mill. When grain arrives at the flour mill, it is first tested to make sure that it is up to standard and that it has not yet begun to sprout. Next it is cleaned. Huge magnets remove ferrous metal objects. Shape graders separate oats, barley and smaller seeds from wheat. Gravity separators remove stones. Air blasts out dust and chaff. Then the grain is softened by adding water.

Once the wheat has been properly cleaned and conditioned, it is blended with other wheats so that the flour that comes out of the mill has a consistent quality day after day.

The blended wheat – or grist – is then passed through a series of fluted 'break' rollers which rotate at different speeds. These are set very precisely so that the wheat is not crushed but sheared open, separating the white insides from the outer, brown, skin.

The result is passed through an arrangement of sieves known as a plansifter and over a sieving table known as a purifier. The white flour – known as semolina – is channelled through a series of smooth reduction rollers for final milling to flour.

Break rollers

The coarser bran with white starch still attached will go back to a second break roller, to separate the white from the brown. In a typical modern flour mill there will be up to four break rollers and 12 reduction rollers. These lead to 16 flour streams, a bran stream, a wheat germ stream and a bran/flour/germ wheatfeed stream.

The whitest flours come from the earliest reduction rollers. The flour gets less white from the later rollers as the proportion of bran increases.

White flour is used for baking. Wholemeal flour is produced by reblending bran, wheatgerm and white flour. Excess bran is sold to make breakfast cereals. And wheatgerm is sold to healthfood stores.

Massey-Ferguson

__A hay baler__ has two sets of belts running in opposite directions, which roll the bale. When it has reached full size, the tailgate opens and the bale is ejected. A simple device, the baler is powered by a tractor (below).

ROBOT GARDENER

In horticulture too, modern computer-driven machinery is taking over from old-fashioned hand tools. Machines for repotting plants automatically have been developed and robots are moving into the market garden. Until now, the various complex operations involved in the propagation of a commercial quantity of plants by tissue culture techniques had to be performed by hand. Now though, computer imaging systems can examine plant cultures and direct a cutting tool to dissect them in the appropriate places. A robot planting tool can then pick up the pieces that can be used for propagation and place them in the growing medium – leaving the microplantlet uncontaminated by fingers, green or otherwise.

Massey-Ferguson

Just amazing!

ONE MAN WENT TO MOW...

BARRY, TREVOR AND ANDY STEMP DROVE A LAWN MOWER 460 KM IN 12 HOURS IN A COMPETITION ORGANIZED BY THE BRITISH LAWN MOWER RACING ASSOCIATION.

Paul Raymonde

BACKHOE LOADERS · COMPACTERS · RIPPERS

BIG DIGGERS

Tony Craddock/Science Photo Library

Giant bucket wheel excavators *– weighing 13,000 tonnes – can move up to 110,000 cubic metres of coal or earth every day. Each bucket (on left of picture) is large enough to hold a small car. The machines are so big that they have to be built on site.*

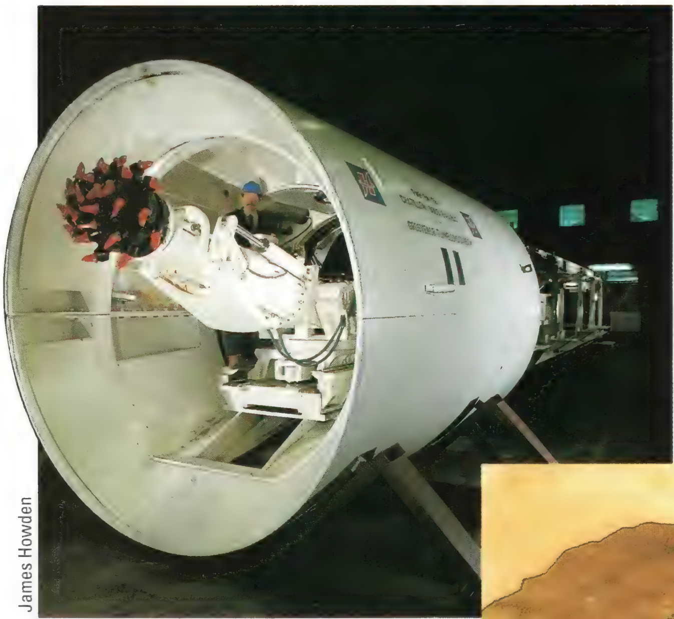
THE MAMMOTH TOOLS THAT are used in major construction projects enable Man to perform engineering miracles that would have taken earlier civilizations scores of lifetimes to achieve. Nowhere is this more evident than in roadbuilding and tunnelling.

To lay a road the terrain first has to be levelled off. In rocky or mountainous areas, major obstacles have to be broken down. On heavily compacted soil or flat rocky terrain, giant rippers are sent in. Each one drags a huge metal hook through the ground to smash through large rocks and loosen the earth. The hook is attached to an hydraulic mount so that it can be forced into the ground at the beginning of its run and lifted out at the end. When this is completed, it is time to send in the bulldozers.

Bulldozers come in various shapes and sizes. Some have huge wheels with massive pneumatic tyres to help with the rough terrain. But the first bulldozers to be used, to clear trees

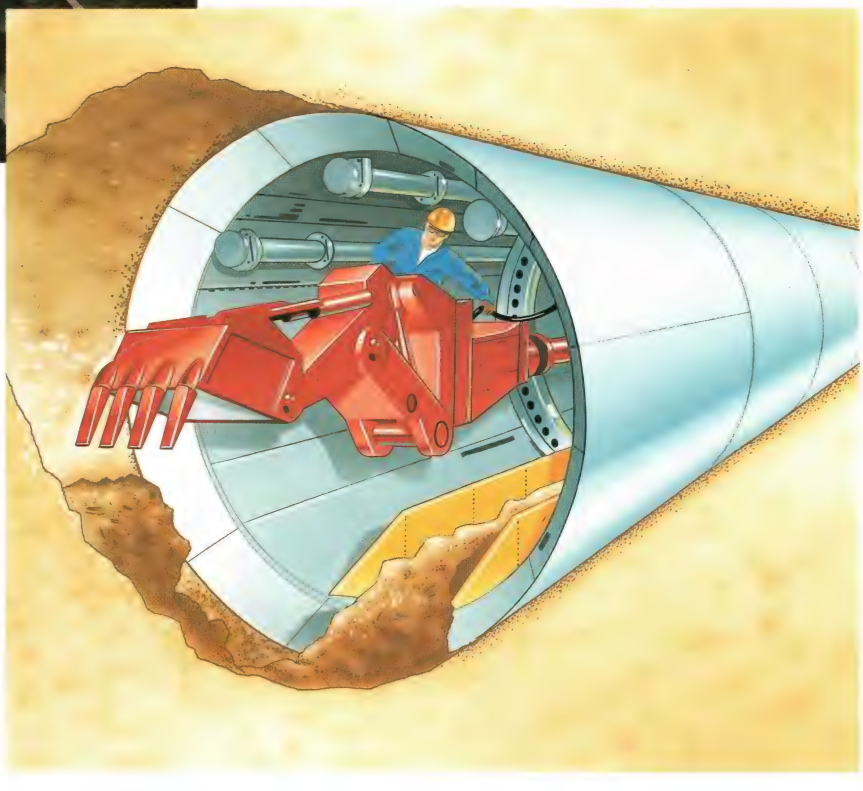
Surface mining machines *remove rocky, compacted ground covering coal and other mineral deposits. These machines can remove up to 14,000 cubic metres of earth every hour. The bucket wheels can be equipped with flat or round-shaft cutters depending on the material to be excavated.*

Krupp Industrietechnik



James Howden

A micro-tunnelling machine*, 3 metres in diameter, used for creating sewage systems. The tungsten carbide cutter head can be changed for a digging bucket (right) according to the type of soil being bored.*



James Howden/Joe Lawrence

and the top soil, have tank tracks instead of wheels to give them better traction on the ground.

Bulldozers have a flat or only slightly curved blade, which can only be lifted a little way off the ground for transportation. This blade is used for pushing debris into heaps, roughly scraping away the top soil or pushing over trees on the site.

Some bulldozers – known as harvesters – carry other attachments instead of blades to rip trees up by the roots or shear them off at ground level. Where digging has to be done, massive excavators are brought in. Again mounted on caterpillar tracks, these carry huge articulated arms with a large bucket-shaped shovel on the end. The arm has three sections, each raised and lowered by a large hydraulic ram. A further hydraulic ram turns the shovel so that it can scoop up rubble.

Swing system

The shovel, arm and cab of the excavator are mounted on a swing system. This is a huge cog, which will swivel the cab on its superstructure so that the shovel can be used to dig at the side of the excavator and be-

hind it, as well as at the front.

Although excavators can be used to shovel earth directly into trucks, usually a small loader is used. This looks much like a bulldozer, but instead of a blade it carries a bucket-shaped scoop that can shovel up a large quantity of loose debris. The scoop is then lifted on hydraulic arms so that the contents can be tipped into the back of a truck.

Hydraulic digger

So-called backhoe loaders have a second hydraulic arm at the back that carries a small excavator shovel so that it can dig as well as dispose of the debris. It also has hydraulic legs that extend downwards to stabilize the loader while it is digging.

The types of trucks used in road building are different from the normal trucks you see carrying building materials on the road. Off-road trucks have huge wheels with massive tyres to help them over rough terrain. The skip, the part that holds the load, is specially designed too. For a start, it has a canopy that protects the cab from falling debris. The base of the skip has a 7.5-degree forward slope with a 16-degree 'duck tail' to stop debris falling out. It also has an 8-degree V bottom to reduce shock when loading. The suspension rides on compressed nitrogen to dampen the shocks that occur when riding over rough tracks.

Once the road bed has been cleared and excavated, huge scrapers level the surface. As well as smoothing off the existing surface, they spread aggregate, gravel and sand evenly across the road bed.

Caterpillar

Caterpillar

***Impact rippers** have a forged alloy steel shank that can shatter even the hardest types of rock. Excavation machines are constructed on a production line (left).*

Caterpillar

Mannesmann Demag

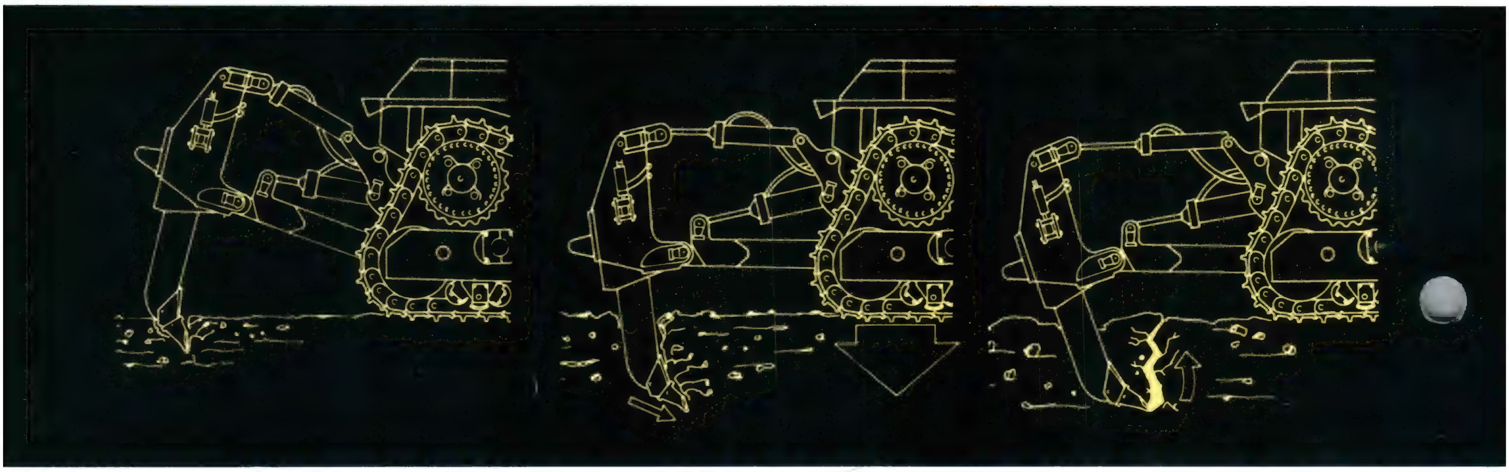
***The gigantic** Demag H 485 mining shovel can fill a 154-tonne truck with only three bucket loads. The operator steers the vehicle with two pedals that are situated at the front of the driving cab (right).*

A compactor is then brought in to compress the road bed to give a solid foundation for the road itself. These have a series of wheels – usually three at the front and four at the back, so that they overlap. The tyres are smooth and pneumatic to even out pressure.

Then the huge 'paving train' moves in to lay a top surface of concrete or tar. Most roads are topped with tar, but some motorways are given a tough concrete surface to withstand the constant battering they receive from heavy traffic. Once the surface has been laid, a compactor is again used to smooth off the sur-

QA Photos

Hydraulic excavators are used to remove topsoil in preparation for major construction projects – in this case the Channel Tunnel. They can be fitted with huge magnets and a variety of booms depending on the size of the job.



The shank of a ripping machine *first thrusts downwards into the ground. The tip is then pulled backwards, exerting pressure by levering against the weight of the machine. The increasing pressure fractures the rock.*

THE CHANNEL TUNNEL

Workers digging the Channel Tunnel used tunnelling machines with a massive cutter head, equipped with 85 tungsten carbide picks. This rotates at up to 4.5 revolutions per minute and advanced in 'cuts' that are 1.5 metres deep. Each one of these cuts generated 86 tonnes of spoil, or excavated earth, that was carried by a conveyor belt directly from the cutter to the rear of the machine. There it was discharged into skips and transported out of the tunnel by truck or train. Once each cut was completed, a concrete ring was constructed behind the machine's shield. The ring came in segments. The three lower sections were dropped into position by a crane and the three upper segments were positioned by an erector. Tunnellers advanced more than 162 metres a week.

face, but this time a sprinkler system sprays water over the wheels, cooling them as they level off the hot tar.

In the case of tunnelling, several different methods are employed, depending on type of soil and the length and breadth of the tunnel. In the case of smaller tunnels, a huge drill is used which has a revolving 'crushing head' that bores through soil and rock. The stem of the drill has a spiralled flange that draws debris back down the shaft and mud is pumped through the tunnel to cool the crushing-head and flush debris out of the system.

Pilot tube

The crushing head is enclosed in a pilot tube, which is lowered on to a guide frame in a starting pit along with a drive unit. Behind the drive unit, a concrete or steel wall is constructed. Huge hydraulic jacks are braced against the wall, forcing the drive unit down the guide frame and the drill bit through the ground. When the pilot tube has completely disappeared into the tunnel, the jacks are released and the drive unit moved back down the guide frame, allowing a section of the tunnel's liner to be dropped in. The drive unit is then restarted and the hydraulic jacks push the liner into the tunnel as the crushing head sinks deeper into the soil. Each time the drive unit reaches the end of the pit and the liner has completely disappeared, the jacks are released, the drive unit moved back, a new section of liner is dropped in and the whole process repeated.

Laser beam

To make sure the tunnel is going in exactly the right direction, the tip of the pilot tube is steerable. A small mirror target hangs down from the roof of the static part of the tube and a laser theodolite sends a beam down the tube. This is reflected off the target and back down the tube where it is displayed on a screen. There, any deviation in the tunnel can be spotted and the steerable tip can be turned to move the tunnel back on course.

Coal

Just amazing!

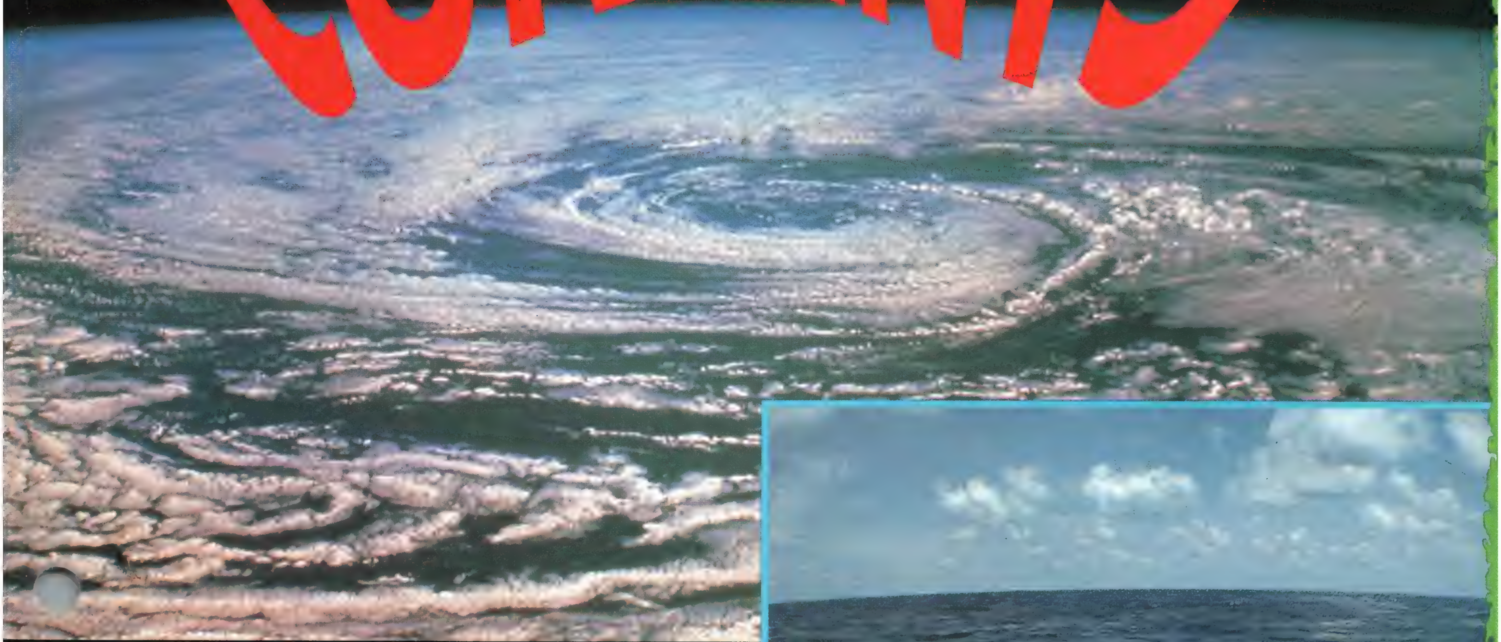
CUTTING IT FINE

A $13 MILLION OPTICS DIAMOND MACHINE IN CALIFORNIA, USA, CAN SEVERE A HUMAN HAIR 3,000 TIMES LENGTHWISE!

Paul Raymonde

THE DOLDRUMS · THE GULF STREAM · WHIRLPOOLS

THE COMMANDING CURRENTS



Tony Stone Photo Library, London

Oxford Scientific Films

Huge, swirling currents of air form themselves into massive cyclonic storms. The most destructive of these, hurricanes, boost winds of over 300 km/h and can be 1,600 km across.

The Sargasso Sea is at the centre of the circulating waters of the North Atlantic. The sea takes its name from the floating sargassum seaweed that collects in the still waters there.

CURRENTS ARE THE DRIVING force of wind and water around the world. They play a crucial role in determining the climate, as well as the routes taken by aircraft and ships. Powerful, rotating currents can also pose a deadly threat in the form of tornadoes, hurricanes and whirlpools.

The Earth's atmosphere is kept in constant motion by the uneven heating of its surface. At the tropics, warm air rises above the Sun drenched equator and moves off towards the poles. Cold air at the poles sinks and moves towards the equator. In between is a temperate zone of rising and sinking air.

Because the Earth spins on its axis, these north and south movements of air are deflected. Winds are diverted to the east in the northern hemisphere, and to the west in the southern hemisphere. The global circulation of air is then further complicated by mountain ranges and the fact that the sea gains and loses heat more slowly than the land.

Trade winds

Although the wind strength and direction at any one place varies a great deal, the general circulation of air around the Earth is fairly predictable. The trade winds, for example, blow steadily westwards from the sub-tropics towards the equator. Where the trade winds meet is a band of still, equatorial air known to early sailors as the doldrums.

To the north and south of the trades are two other belts where there is often little wind. These are the horse latitudes, so called because sailing ships becalmed there, in blazing heat, would throw their horses overboard. At still higher latitudes are the westerlies, bringing warm air from the southwest in the northern hemisphere and from the northwest in the southern hemisphere.

The 'Roaring Forties'

Large continental land masses in the north disrupt the westerlies and cause them to vary in strength and direction. But in the south, where there is more open ocean, the stronger westerlies have earned themselves the name the 'Roaring Forties'.

Winds, together with tides and the

Sun's heat, also play a major role in creating ocean currents. In general, ocean currents move in the same way as the world's major wind systems.

Ocean gyres

Geographers have identified around 40 important currents in the ocean surface. Many of these link up into five giant loops of moving water, called gyres, that circle the various oceans. For example, the North Atlantic gyre starts north of the equator where trade winds and the Earth's spin steer the North Equatorial Current west towards northern South America. This current's water joins the Gulf Stream – a warm ocean river over 600 metres deep and 60 km wide. In places it moves at 160 km a day, bringing warm water from the Gulf of Mexico to the shores of western Europe. The Gulf Stream also gives a free ride to millions of baby eels that hatch out in the Sargasso Sea off North America.

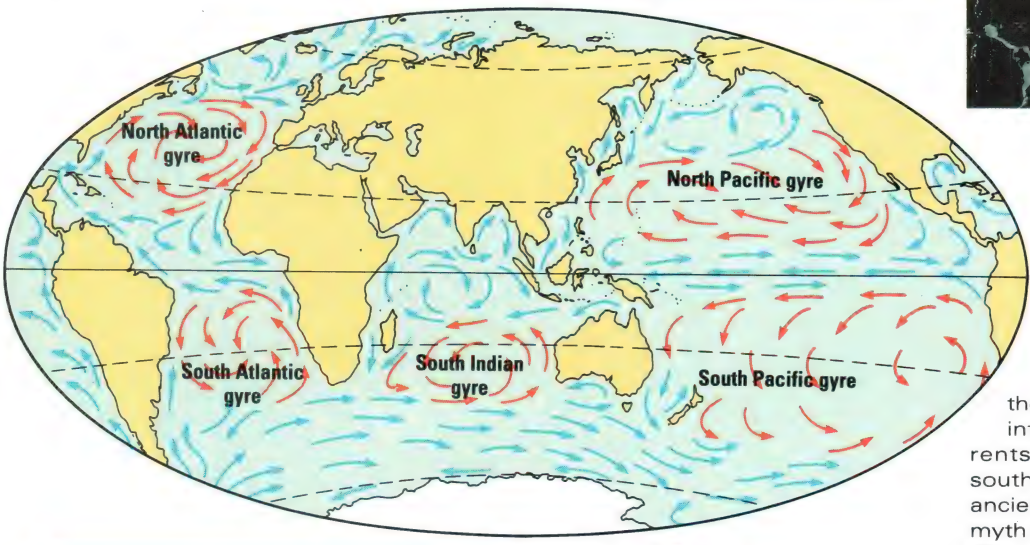
In 1947, the Norwegian explorer Thor Heyerdahl showed that South American Indians could have colonized the islands of Polynesia using primitive boats carried along by the South Pacific gyre. Aboard his balsawood raft Kon-Tiki, he and his five-man crew successfully sailed 6,900km from Peru to Tahiti.

PaulWilliams

***European eels** spawn in the Sargasso sea. The young elvers then hitch a ride back to Europe on the Gulf Stream.*

***A whirlpool** forms at the foot of a cliff where the tide surges out through a tunnel at Aber Foel Fawr, Ramsey Island, Wales.*

Jane Burton/Bruce Coleman Ltd



***The rotation of the Earth** causes five huge circulating masses of water – or gyres – in the oceans. Sailors have taken advantage of these currents for centuries.*

The Maelstrom

A large swirling vortex, or whirlpool, is among the most terrifying obstacles to ships at sea. The Maelstrom (Dutch for 'whirling stream'), for instance, is a giant whirlpool that sweeps back and forth between two islands of the Lofoten group off the northwest coast of Norway. It has been a menace to sailors for hundreds of years. The Maelstrom arises from rocks and tides that oppose the main ocean current and becomes especially dangerous when the wind blows against it between high and low tides.

Another famous whirlpool, the Garofalo, forms because of the interaction of winds and tidal currents along the coast of Calabria in southern Italy. Known to seafarers in ancient times, it is referred to in Greek myth as the monster Charybdis.

Jane Burton/Bruce Coleman Ltd

Niagara Falls

Other major whirlpools occur in the strait between Sicily and Italy, in the Naruto Strait connecting the Sea of Japan with the Pacific Ocean and near the Hebrides and Orkneys off the coast of Scotland. Probably the one most visited is Whirlpool Rapids in the gorge below Niagara Falls. This is formed by water circulating round a worn-out basin to the side of the river's main course.

RAINING FROGS

Reports are not uncommon of frogs, fish, crabs, and other small animals literally falling out of the sky. For example, in June 1984, the owner of a service station near Thirsk, North Yorkshire – 45 km inland from the British coast – found winkles and starfish covering the forecourt of his garage. The explanation may be that these small creatures were picked up by a whirlwind or waterspout along the east coast of England. Then they were carried aloft for perhaps an hour or more in the powerful updraft of a thunderstorm before dropping back to Earth.

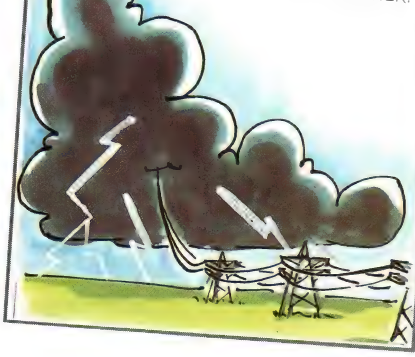
Rex Features

***Thor Heyerdahl** rode the South Equatorial Current in his balsa wood raft Kon-Tiki, proving South American Indians could have colonized Polynesia.*

Just amazing!

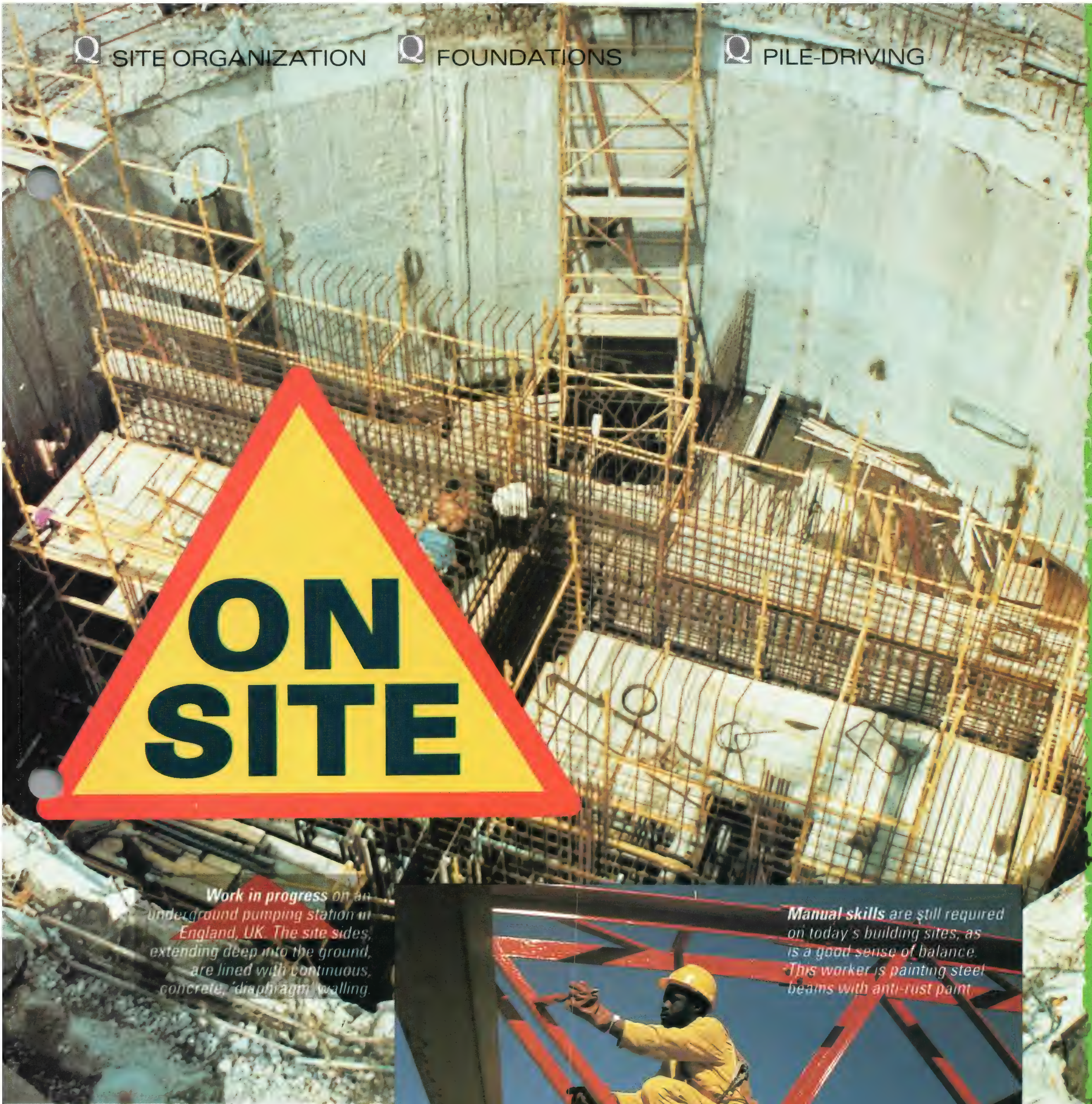
BLOW ME DOWN

A BIG TROPICAL STORM – 1,600 KM ACROSS WITH WINDS UP TO 400 KM/H – CAN GENERATE 100 TIMES MORE POWER THAN ALL THE WORLD'S POWER STATIONS PUT TOGETHER.



Paul Raymonde

ON SITE



Work in progress *on an underground pumping station in England, UK. The site sides, extending deep into the ground, are lined with continuous concrete, 'diaphragm' walling.*

Charles Haswell and Partners

Manual skills *are still required on today's building sites, as is a good sense of balance. This worker is painting steel beams with anti-rust paint.*

Tony Stone Photo Library, London

THE BUILDING SITE IS A temporary factory that exists only until a construction project has been completed. And not only buildings are involved – major projects may include roads, bridges, dams, airfields, pipelines and even tunnelling.

First, a site must be examined for its suitability for the proposed building project. The site may have to be drained – if the soil is waterlogged, there is a danger that structures built on it will tilt. It is important to find out what the site was previously used for – possibly tunnelling or the dumping of waste. Waste not only makes the ground liable to sink, but may include harmful chemicals and even generate gases, such as methane. Many sites are being built on for the second time.

Bore holes are drilled so the subsoil and layers of rock beneath the site can be examined. Decisions can then be made on the depth of foundations, and on whether steel or concrete piles need to be rammed into the earth as deep foundation supports.

Once the building site has been surveyed, an architect will draw up a set of plans called 'blueprints' that must be followed to the millimetre. The surveyor then uses the blueprints to mark up the site so all boundaries,

Construction *of a new shopping centre in Basingstoke, near London, UK. The surface of the site has been levelled, and excavated soil and rock transported away.*

This bridge *at Abu Dhabi in the United Arab Emirates is being put together from units of pre-stressed concrete. High-tensile steel wires inside each slab compress the concrete so it can carry heavy loads without cracking.*

Tony Stone Photo Library, London

Tony Stone Photo Library, London

foundations, pipelines and everything else will be exactly in position. It is also the architect's responsibility to detail all the materials to be used and to calculate the stresses and strains that the materials will have to bear. The contractor draws up a 'Master Programme' – a timetable for the project, from beginning to end.

Master plan

Access to the site by road and rail must be considered. In some projects, such as airfields and roadworks, large amounts of earth have to be transported from the site. Areas for stores, spoil heaps and machinery parking are planned. Temporary structures for the building team – storerooms, plant repair shops and supervisors' offices – will all be needed.

Before building begins, the site must be cleared. Any unwanted buildings already on the site are demolished, trees and all plants are pulled up and the top soil is removed (often to be put on one side and reused later). On a very large site, sewers, drains, power lines and even telephone lines may have to be rerouted or protected.

Before the foundations are laid, a pit must often be dug. Sometimes, excavation is finished off by hand-held pneumatic drills, when machines cannot reach down far enough, or manoeuvre within the confines of the hole. The pit sides are supported by sheets of steel (trench sheeting), steel sheet piles or wooden boards.

Hole in the ground

Any building is only as strong as its foundations. However well built it may be, the platform beneath it must be able to prevent it sinking into the ground. When a house is being built, the ground area is excavated and trenches, up to a metre deep, are dug in a shape corresponding to the outer and inner walls of the house. A layer of concrete (the strip foundation or footing) at least 250 mm thick is laid at the bottom of the trench, then concrete blocks and sometimes bricks are laid in the trench until they reach a point just below the floor level of the house. 'Floor level' is a 5 cm-thick screed laid over the groundslab.

Solid foundations

At this point, the ground area of the house is filled with hardcore (rubble) and covered with a sheet of plastic to keep out damp and a concrete platform called a groundslab or oversite that is levelled off. Concrete is a mixture of cement and aggregate – that is, different-sized grades of rocks or stone. It is usually mixed on site.

In bigger constructions, a mesh of steel may be added to reinforce the concrete. Where a building is on unstable or marshy ground, deep bearing piles (pillars) of concrete or steel may have to be sunk, upon

SKELETONS OF STEEL

New Builder

Many multi-storey buildings are constructed around a framework of steel columns and beams that act as load-bearing skeletons. Steel frames are bolted, welded or riveted together. A tower crane or guyed derrick erects the frame. Bolted frames are put together by workmen (as here, on the site of a new sports centre in Sheffield, UK) using spanners or torque wrenches. The bolts are made of high-tensile steel that is stronger than the softer steel in the beams. They can be altered or dismantled more easily than riveted frames, where red-hot rivets are inserted into holes in the steel by special pneumatic or hydraulic tools. Welding has now overtaken riveting in popularity. The region where two pieces of metal touch is heated until the metal melts and the two pieces fuse together. Additional metal may have to be added to produce a good join.

Watson and Hillhouse (Plant Hire) Ltd/Joe Lawrence

Plettac UK

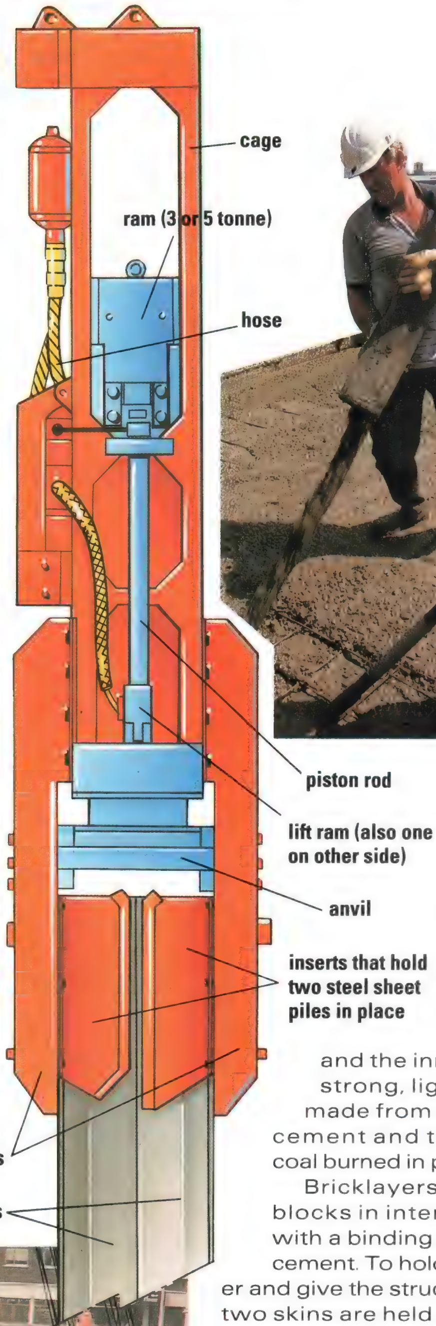
To protect this building site (and the workers on it) from the elements, a steel tubular frame has been erected over the site and then draped with flameproof, PVC-reinforced, nylon sheeting.

which the foundations are laid. This will give the building a secure base.

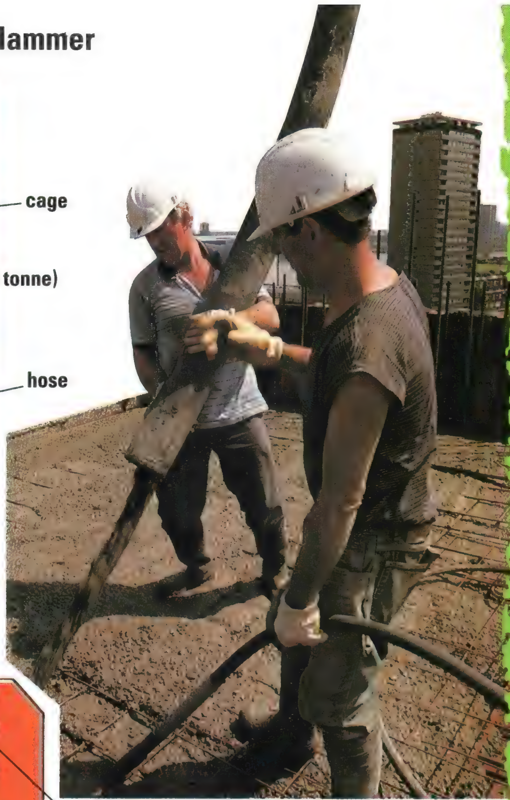
Once the foundations are laid, the main supporting walls are built. For strength and insulation, brick walls are made up of two 'skins' with a gap in between. The outer skin is built of bricks or of concrete blocks that are later coated with sand and cement, and the inner skin is built of strong, lightweight blocks made from a combination of cement and the residue from coal burned in power stations.

Bricklayers lay the bricks or blocks in interlocking courses with a binding layer of sand and cement. To hold the walls together and give the structure strength, the two skins are held together at intervals by a series of metal ties built into

Hydraulic Drop Hammer



A pile-driver drives piles – steel, concrete or timber columns or sheets – into the ground. Sheet piles hold back the sides of pits or trenches. Bearing piles support the weight of a building. The hydraulic-powered drop hammer pushes sheet piles (held in place by inserts) into the ground with a heavy ram.



The Builder Group

Wet concrete is poured over a steel mesh to make slabs. Almost all concrete is reinforced with steel rods or wires.

Tony Stone Photo Library, London

Using a crane, workers position the collar of a buried pile. Behind them, another machine is about to sink a concrete bearing pile into the ground.

Just amazing!

EARTH MOVERS

THE EARTH MOVED ON THE WORLD'S BIGGEST SITE, IN SAUDI ARABIA, WOULD BUILD A WALL 7 METRES WIDE AND 1 METRE HIGH AROUND THE EQUATOR.

Paul Raymonde

the brick or blockwork.

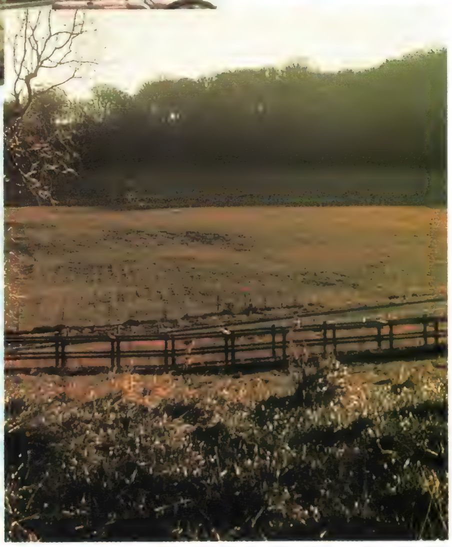
When the walls have reached the height of the first storey, carpenters lay out timbers called floor joists that must be strong enough to withstand heavy loads, including internal walls. At this stage too, any metal girders that need to take heavy weights are loaded into position by site-workers or a fork-lift truck or crane.

***A bridge,** pushed by hydraulic jacks, slides into position. The rate at which the bridge moves is monitored on a television screen.*

British Rail

COVERING UP CONSTRUCTION WORK

Shell



When an oil refinery was built at Stanlow in Cheshire, UK, crude oil had to be transported from a buoy off Amlwch on the Isle of Anglesey, where supertankers unloaded their cargo of oil. A 125 km-long pipeline cut a swath across the countryside of north Wales and north-west England. This is just one example of the damage construction projects can do to the environment – but, in this case, also of how such damage can be remedied. Along much of the pipeline's route the earth, top soil and turf has been put back, returning the land to its former state.

As a building goes up, scaffolding is erected. This is made of a strong tubular steel framework, clipped together and filled with wooden boards to make walkways for the builders.

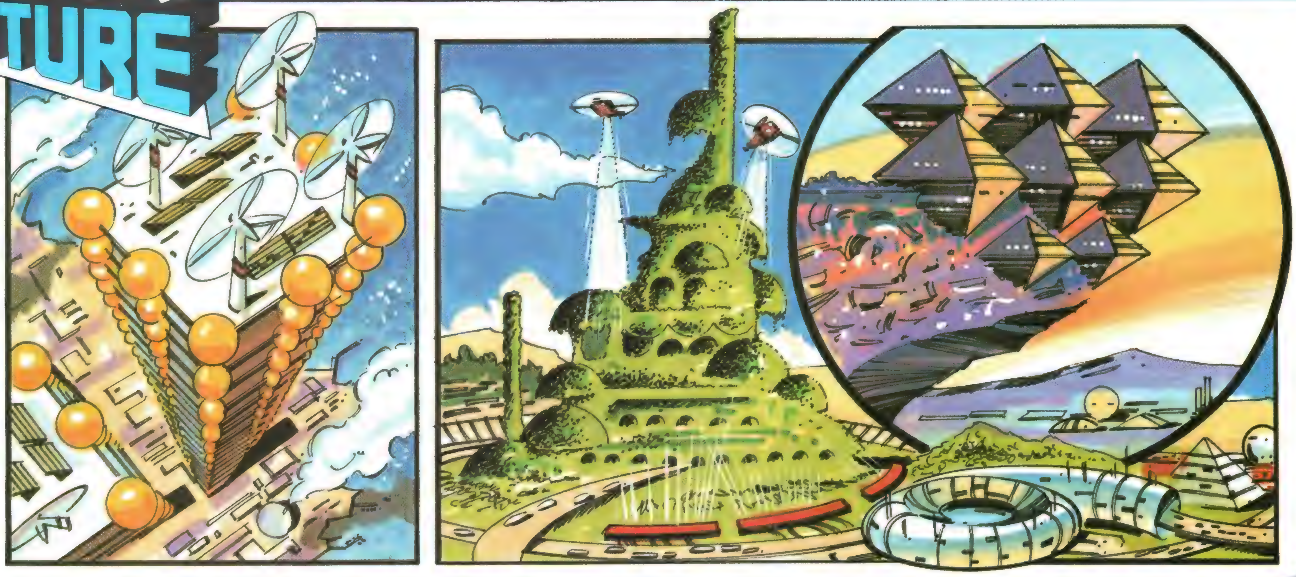
Off the ground

In a house, the skeleton of the roof is usually made from pre-formed timber roof-trusses, held together at the joints with spiked steel plates. This framework is covered successively with a lattice of wooden battens, sheets of bituminous felt and tiles.

Once the roof is on, the internal work can begin. Carpenters, glaziers, plumbers and electricians move in to finish the building.

INTO THE FUTURE

TOMORROW'S MATERIALS



▲ *Future building projects will not always make use of today's materials. Housing units stacked high into the sky may be constructed from soya-based plastics.*

▲ *Buildings at desert oases may be made of a 'hydromulch' of seaweed, cement, plant seeds and water. When watered, the buildings should 'grow'.*

▲ *'Trash housing' will incorporate metal, glass and rubber that is currently thrown away as rubbish, and be supplied with solar power and methane gas.*

Joe Lawrence

COASTLINES

At Big Sur, an 80-km-long stretch of coast south of Carmel, rocks project above the waves where California's Santa Lucia range of mountains swoops down into the Pacific Ocean.

Hutchison Library

Seaweeds (marine algae) vary in size from a few centimetres to huge kelps as long as 60 metres.

Warren Williams/Planet Earth Pictures

FORCES OF LAND AND SEA clash daily on coastlines around the world in a mighty, never-ending battle. On some stretches of coast, powerful waves pound relentlessly against rocky cliffs, gradually gnawing them away. But elsewhere the struggle may go the other way, with the land pushing out into the sea.

The presence of rocks or cliffs on the shoreline is a clear sign that the sea is winning. On stormy days, the wind whips up the surface of the sea into large waves that smash against the shore, punching air into the rocks. As the waves retreat, the squashed air expands, loosening chunks of rock that eventually break away.

Waves also hurl shingle, pebbles and sand against the land, causing further damage. Even plain seawater contains dissolved chemicals that enable it to attack coastal rocks such as chalk and limestone.

Overhanging cliffs

The base of a section of coastline is the first to be eroded. But as the notch deepens, the overhang above grows in size and weight until, in time, it too collapses. In this way, over thousands of years, the most gently sloping coast can be turned into a series of tall, rocky cliffs. The highest cliffs in

Doug Allan/Science Photo Library

***Caves** on the edge of the Ross Ice Shelf, Antarctica. An ice shelf is a sheet of floating ice attached to a coastline. In time, the ice caves will collapse and large pieces of ice will break off and float free as icebergs.*

Tony Waltham

***Black sand beach,** Kalapana, Hawaii. The beach is black because it is made up of fragments of lava from Hawaii's volcanoes.*

the world, on the north coast of Molokai in the Hawaiian Islands, soar vertically for 1,005 metres.

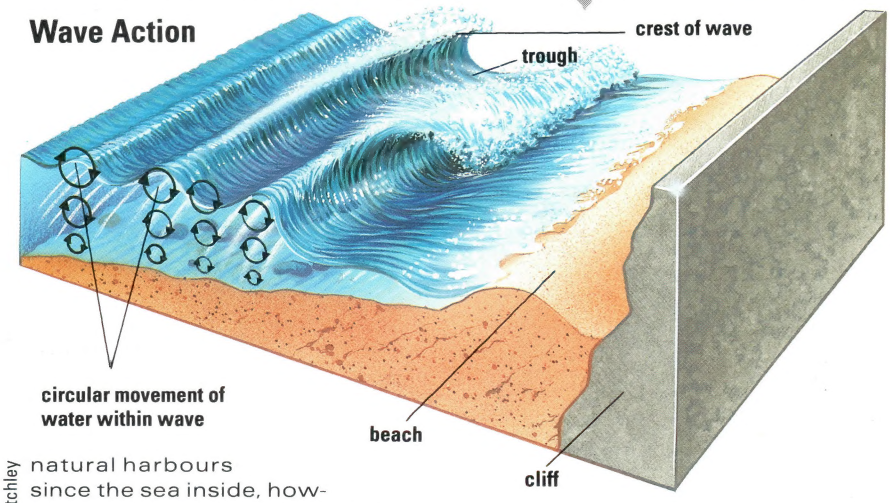
Rocks of different hardness erode at different speeds. In Britain, a stretch of the Yorkshire coast between Flamborough Head and Spurn Point is made of such soft clay that it wears away at a rate of 2 metres a year. Old maps of this region show many towns and villages that have now fallen into the sea.

Bays and coves

Since softer rocks are eroded faster, they give rise to bays separated by peninsulas of harder rock. In some places, the sea may make a small opening in a ridge of hard rock, then eat away the softer rock behind to form a cove. Such places make ideal natural harbours since the sea inside, however rough outside, is always calm.

***Each wave** is pushed forward by the wind and down by gravity. Particles of water move up, forwards and downwards with the crest of a wave, then backwards and upwards with the trough that follows.*

Wave Action



Simon Critchley

Any cracks or joints in cliff rocks are worn away faster than the rest of the cliff-face. The waves slam into these gaps and gradually widen them to make caves. As the water dashes against weak points in the cave roof, it may wear a hole right through. At high tide waves surge up this passage, known as a blowhole, and seawater sprays out like a geyser.

If caves form back to back on both sides of a headland, eventually they may meet to make an arch. Later, when the roof of the arch falls in, a pillar of rock called a stack is left, separated from the mainland by a narrow channel of sea.

The debris produced by coastal erosion is transported away from where it falls by waves and currents. Heavy rocks and pebbles are rolled along the sea bed, slowly being ground down into smaller particles, which are carried suspended in the water. All the time, the debris is sorted according to size so that there is a gradual progression from large boulders at the base of cliffs to fine sand further down the beach.

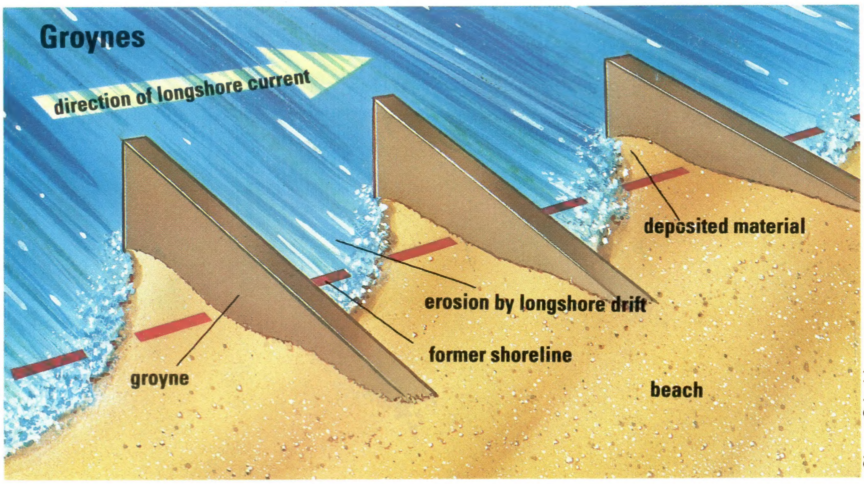
Typically, the wind drives waves up a beach at an angle. The waves then return directly down the steepest slope. As a result, material is moved along the beach in a zig-zag manner known as longshore drift. To help prevent this movement, barriers called groynes are often set up at regular intervals between the high and low tide marks.

Material carried by waves and currents is deposited only when some obstacle slows down the movement of water. Projecting headlands, rivers flowing into the sea, and wind and

SEA TURTLES

Jany Sauvanet/NHPA

Every two or three years, female sea turtles return to the beach where they were themselves hatched, to lay their eggs. The turtles often arrive in large groups, sometimes covering a stretch of shore in a 'carpet' of turtles. Each female (such as the giant leatherback turtle, above) digs a hole in the sand with her back legs and then lays as many as 200 eggs. Having covered the eggs with sand and firmly packed it down, the female returns to the sea. Between two and three months later, the eggs hatch and the baby turtles make their perilous dash for the sea. Picked off by predators such as seabirds, crabs, and humans, only one or two turtles from a nest may survive.



Simon Critchley

Barriers jutting *out into the sea, called groynes, are erected between high and low tide marks to stabilize a beach that is being shifted or destroyed by longshore currents. These carry sand and shingle along the length of the beach.*

currents moving against the main flow, all have the effect of causing seawater to drop its load.

Beaches are the most obvious feature of deposition. These tend to be widest along lowland coasts and narrowest at the foot of steep cliffs.

On the beach

The colour and coarseness of beaches depend on their source. The black sand on Hawaiian beaches, for example, comes from the lava spewed out of the volcanoes of these islands. Some beaches in the Bermuda group, on the other hand, are pale pink because their sand is stained by a type of red plankton.

On gently sloping shores, bars are a common sight. These ridges of sand or shingle, running parallel to the coast, form when waves stir up loose material from the seabed. If the waves then break before they reach shore, the suspended particles in them fall and build up, first as a submarine bar, then as a strip of land above sea level.

The famous beach at Miami, Florida, is an offshore bar with a lagoon behind it. Bars are also found at the mouths of estuaries, when a river drops a lot of sand or mud before flowing into the sea.

The margin of sea and land is a challenging environment for the animals and plants that have to live there. Creatures inhabiting the zone between high and low tide must be able to survive both underwater and exposed to air. They also have to endure the battering of waves and drastic changes of temperature, as rockpools are warmed by the Sun and then cool down rapidly at night, .

Shore life

Some seashore animals, like the limpet, mussel and barnacle, have tough shells and special organs that allow them to cling on firmly to rocks at low tide. Others, such as cockles, razor shells, and lugworms, bury into moist sand or mud for protection.

Seaweeds, too, are specially adapted to a life of saltwater and air. Unlike land plants, they have no stems, leaves, or roots. Instead, they absorb the nutrients they need directly through their body walls. They also have no means of support so that when exposed at low tide they hang limply over the rocks. Some seaweeds anchor themselves to the seabed by means of rootlike parts called holdfasts, while others float freely in the water on pockets of air.

Dan Farber/Science Photo Library

Hurricane Carol *lashes into North America's east coast, as part of the erosion process that is causing the coastline to retreat. At Cape Hatteras, North Carolina, USA, for example, the shoreline has moved back more than 426 metres in 110 years.*

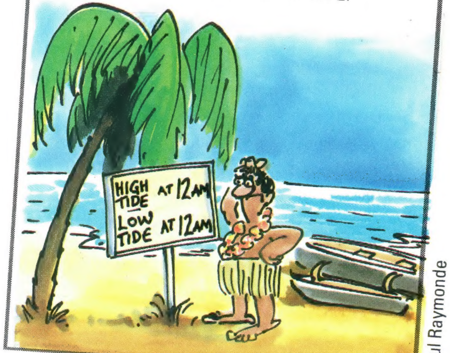
Robert Harding Picture Library

A sea stack *emerges when surrounding softer rock is eroded away. James Bond Island, here, is close to Phuket off the west coast of Thailand. Part of* The Man with a Golden Gun *was filmed here.*

Just amazing!

HIGH TIDE

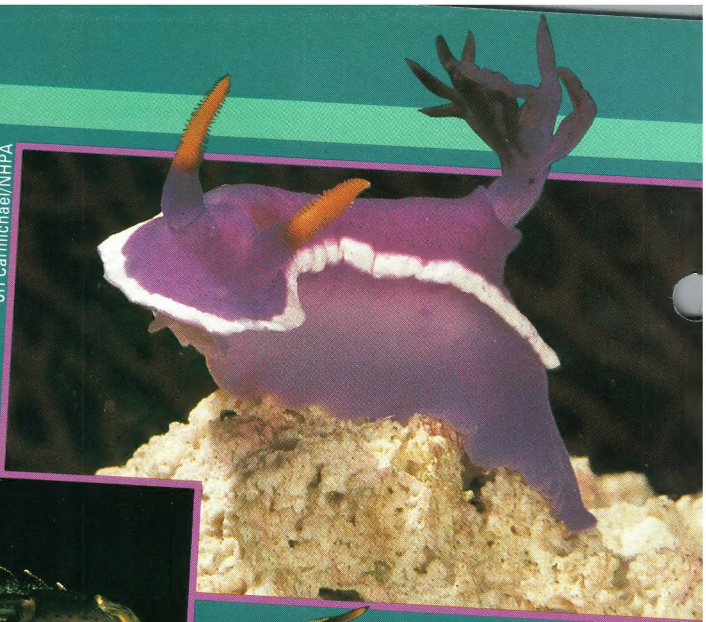
THE WORLD'S BIGGEST MEAN SPRING TIDE RANGE – 14.5 METRES – IS AT BURNCOAT HEAD, NOVA SCOTIA, CANADA. TAHITI, BY CONTRAST, HAS VIRTUALLY NO TIDE.



Paul Raymonde

Many bristle worms live in tubes built from sand, mucus or carbonate of lime. The worm emerges from its tube to look for food, trapping water-borne particles of animal or vegetable matter in its bristles.

JH Carmichael/NHPA



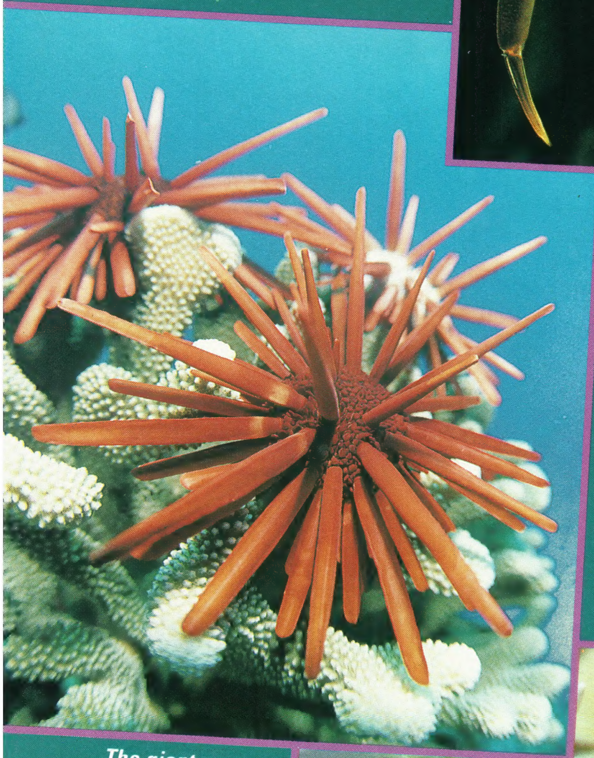
The bright colouring of this sea slug warns predators that it will secrete toxic substances when threatened.

L Campbell/NHPA

A female shore crab, with a mass of orange-coloured eggs attached to her abdomen. She carries the eggs for 12-18 weeks before they hatch into tiny transparent larvae.

H Voigtman/Planet Earth Pictures

Sea urchins have a rigid internal shell out of which emerge spines and tiny claws. 'Tube-feet', used for walking and feeding, protrude from the sides of the shell.



Starfish feeding on mussels. The starfish's stomach, extruded through its mouth, covers and then digests the unfortunate mussel.

R Waller/NHPA

J Burton/Bruce Coleman Ltd

Oarweed is one kind of kelp, a large brown seaweed. It grows off most European coasts, below the low-water mark . These primitive plants, which can grow up to 3 metres long, are edible and are also used as fertilizer.

G Douwma/Planet Earth Pictures

The giant green sea anemone paralyses a small fish or animal with stinging cells on its tentacles and then pushes the catch, whole, into its sac-like body.

J Foott/Bruce Coleman Ltd